GLACIERS OF GLACIER NATIONAL PARK

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GLACIERS OF GLACIER NATIONAL PARK.[1]

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INTRODUCTION.

Glacier National Park derives its name and much of its interest from the presence of many small glaciers. Very much of the grandeur of its wonderful Alpine scenery, the final sculpturing of the great mountain valleys and of the amphitheaters at their heads, and the production of the basins of its many beautiful lakes are due to the action of the more extended glaciers of the past.

There are in the park about 90 small glaciers ranging in size from Blackfeet Glacier, with its 3 square miles of ice, down to masses but a few acres in extent yet exhibiting the characteristics of true glaciers. The most easily accessible of these from the beaten trails are the Blackfeet and Sperry Glaciers and the small glaciers at Iceberg Lake and at Ahern Pass. Some of the others can be reached by tourists who are willing to undergo the exertions of mountain climbing. Among these are Grinnell, Chaney, Shepard, Vulture, and Carter Glaciers, and one or two at Brown Pass. (See map facing page 17.)

After examining these features one can easily picture to himself, as he looks down the valleys, the great rivers of ice which in ages past cascaded from the cliffs below the upper cirques, converged as tributaries from the many branch valleys, and united in great trunk glaciers. In imagination he can see these great glaciers many hundreds of feet in depth filling the great mountain valleys from side to side, and deploying thence upon the bordering plains. He seems to see these mighty engines plucking away the rock ribs of the mountains, smoothing, grinding, and polishing the irregularities and sweeping away the débris to be spread on the plains below. These glaciers developed and extended three times and, after each development, the congealed masses melted away on the return of milder climatic conditions, until at length only the small cliff glaciers of the present

[1] The descriptions of the glaciers and the discussion of the glacial phenomena presented in this paper are based upon studies by the writer, made during the summers of 1911, 1912, and 1913 for the United States Geological Survey, in and adjacent to the park. He was assisted in 1911 by J. Elmer Thomas; in 1912 by Eugene Stebinger, and in 1913 by Clifton S. Corbett. Not all of the pricipal glaciers have been examined and much of the area of the park remains to be covered by the geological survey. The presentation in this paper is thus only preliminary in character and is intended rather as a popular than a technical discussion.

For further treatment of the physiographic development of the region one should refer to the companion pamphlet issued by the Department of the Interior, entitled "Origin of the scenic features of Glacier National Park, Montana," by M. R. Campbell. This publication may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 15 cents.

day are left lurking in the protected recesses at the heads of the capacious valleys.

Many of the rock-walled amphitheaters are no longer occupied by ice, but from all there issue streams fed by the melting snow or ice. These plunge over the cliffs in beautiful foaming cascades and rush on down the mountain gorges. The melting glaciers left many inclosed basins large and small, and in these the waters rest a while and mirror in their crystal depths the dark green of the surrounding forests, the rich colors of the rugged mountain walls, and the deep blue of the cloud-flecked sky. On again from lake to lake the waters flow and finally start down their long courses to the sea to merge at length with the chill waters of Hudson Bay, the balmy tides of the Gulf of Mexico, or the rolling billows of the Pacific.

Compared in size with the great glaciers of Alaska the glaciers of Glacier National Park are insignificant. They are even surpassed in size by those of the Alps, of the Canadian Rockies, and of Mount Rainier, Washington. They are, however, though small, among the best examples of this interesting type of phenomena now existing in the United States. They have also a splendid setting in magnificent Alpine scenery, unsurpassed in grandeur anywhere. Hidden away in the recesses of the mighty mountain ranges these rare and wonderful features form a climax to many of the interesting trips open to the tourist.

BLACKFEET GLACIER.

General relations.—The largest glacier of the park, one of the most readily accessible, and one exhibiting in fine development most of the features particularly characterizing glaciers is the Blackfeet[1] (title-page and fig. 13, p. 24).

From Gunsight Camp, an easy trail leads southward about 1 mile, with an ascent of about 500 feet, to the foot of the main lobe of the western part of the glacier. Climbing the morainal embankment which obstructs the view one looks out on a scene of surpassing interest and grandeur. The distance across the glacier on a nearly east-west line, is 3.2 miles; the maximum extent southward from the front of the eastern lobe to the crest of the snow-covered Continental Divide on Blackfoot Mountain is 1.6 miles; the distance from the front of the western lobe to the divide southeast of Jackson Mountain is nearly the same; the approximate area of the entire mass is 3 square miles. Lying in a depression in the mountain slope, having a greater extent laterally than in the direction of movement, and having no lobate extension down the valley, it is what is known as a cliff glacier.

[1] In an article in the Scientific American Supplement, Sept. 23, 1899, George B. Grinnell states that in 1891 he took to the head of St. Mary River the first party that had ever visited it so far as known. In 1895 in company with a Government commission he again visited the head of the valley. In 1897, in company with J. B. Monroe, he climbed Jackson Mountain, and in 1898 he ascended Blackfoot Mountain and from it beheld the glacier to the south which had been seen in 1883 by Prof. Raphael Pumpelly on a trip across Cut Bank Pass and which since that time has been known as Pumpelly Glacier.

Banked against the upper mountain slopes is the snow field, or névé, from which the glacier originates. Here what is left of the snows of many winters has become compacted and changed to granular ice. When such ice accumulates to a sufficient thickness internal movement begins. Such moving ice constitutes a glacier. High up on the slopes there may be seen, in places, a line of crevasses which marks a break between the moving ice and the stationary part of the névé. Such a crevasse is called the "bergschrund" by the Germans. The main or eastern part of the glacier nearly fills the upper cirque extending almost to the crest of the cliff at the head of the valley southwest of Citadel Mountain. Beneath the western part of the glacier the slope nearly coincides with the inclination of the rock and there is no marked break forming a cliff.

Moving down this slope, the ice of the western part of the glacier gathers in from all sides to a central stream. The lower 0.7 of a mile of its extent is thus contracted to a narrow lobe about 1,600 feet in width. This part is easily accessible to the tourist and here may be observed most of the typical characteristics of alpine glaciation.

Moraines.—Along the front of the glacier throughout nearly its whole extent is a great embankment or moraine of clay and bowlders which was formed by the piling up of rock débris carried forward by the moving ice. The greater part of such material, which is known as drift, is embedded in the lower part of the ice when being transported, but a smaller part is borne upon its surface, having fallen from the mountain slopes. When released by melting at the glacial front the drift accumulates and may be crowded up into a ridge. Much of the morainal material piled up along the front of the Blackfeet Glacier probably accumulated some time ago when the ice was thicker and somewhat more extensive. A person standing on the moraine where it is most readily accessible from the trail sees the main lobe of the western part of the glacier extending down between two great morainal embankments. The glacier thins to a frontal margin at an elevation of about 5,725 feet above sea level. The moraines, however, continue some distance farther down the slope and there they curve together and join in one continuous loop, showing that at some earlier date this lobe had a somewhat greater extension. The distance from the end of the morainal loop to the front of the ice was not measured, but it is estimated as about 1,000 feet. Across the end of the loop trees are growing, but nearer the ice there is no vegetation and the bare slopes are very steep and in places even precipitous as the result of slumping and sliding of the clay and bowlders. The moraine ranges in height from 20 to 100 feet with an uneven, ridged crest varying from a few feet to a few yards in width, so that it is a striking topographic feature. For some distance from the lower end of the ice lobe the northwest margin has been melted back 50 to 100 yards, from the foot of the inner slope of the moraine, expos-

ing the bare, smoothly polished, and striated ledges of rock over which the ice formerly extended. Farther west up the slope the thin ice extends to the foot of the moraine. On the east side of the lobe the ice extends to the foot of the moraine but the crest of the latter towers high above it.

3 *Movement.*—That the ice is not stagnant but moving slowly forward may be easily demonstrated. Opposite the sharp curve in the moraine at about 6,350 feet above tide there is a change in the slope. Looking into a low ice cave at this place one can see far under the glacier. Here the ice after passing the crest of the ledge extends free a few feet above the rock over an area of many square rods before breaking down. An iron spike set in the ice at this place on August 19, 1913, showed a movement of $3\frac{1}{4}$ inches in the first 24 hours, of three-eighths inch in the next 5 hours, and of $3\frac{3}{8}$ inches in the succeeding 25 hours and 25 minutes. This gives an advance of 7 inches in 54 hours and 25 minutes.

Owing to the steepening of the slope at this place the ice is much crevassed. Some distance farther up the slope is another broad zone in which the ice is much broken by crevasses. A second spike set in the ice wall of a cavity at a point N. 85° W. of the peak of Jackson Mountain and about 6,725 feet above tide near the lower border of the upper crevassed zone, showed an advance of $1\frac{1}{8}$ inches in 24 hours, and in the succeeding 30 minutes an additional advance of one-eighth inch, the time being in the middle of a warm, bright day.

On August 21, a marked pebble was set in the ice at a point in front of the glacier N. 75° E. of the peak of Jackson Mountain and six-tenths of a mile northeast of the 6,879-foot bench mark. The ice at this point advanced seven-eighths inch in $4\frac{3}{4}$ hours during the warm part of a warm day.

This is a crude method of measuring the rate of movement, and the results can not be regarded as a true index of the rate in all parts of the glacier. No attempt has yet been made to obtain accurate measurements of the movement in this or any other glacier within the park, and no estimate of the total yearly advance can be made from measurements as few and so crude as these. The rate of glacial movement varies greatly with temperature and other climatic conditions, being more rapid on warm moist days than on cold and dry days.[1]

4 *Crevasses and ice cascades.*—Ice has little elasticity, so that crevasses are produced in the surface of a glacier by tension at places beneath which are considerable irregularities or steepenings of the rock slope down which the ice is moving. As the broken ice moves slowly forward

[1] The rates of average daily movement of glaciers in the Canadian Rockies and Selkirks range from 2 to 20 inches, of the great Alaskan glaciers 1 to several feet, as much as 7 feet on Muir Glacier. In the Swiss Alps the rates range from 1 or 2 inches to 4 feet or more per day.

a succession of fractures constantly takes place in the same relative positions. There is a regular cycle in the development of crevasses which is well illustrated in the upper crevassed zone on the western part of Blackfeet Glacier (title-page). In the upper part of the central belt the cracks appear; farther down the widening of the cracks by melting breaks the surface into flat-topped tables. As the crevasses gradually widen the intervening tables narrow until they become sharp-crested ridges where one can scarcely find footing. Following this the sharp ridges may be broken into pinnacles or seracs, such as may be seen at one place near the ice front south of Citadel Mountain. Finally the ridges are lowered by the melting and gradually disappear. With the closing of the crevasses below, the surface of the glacier thus becomes again smooth and passable. Crevasses are also sometimes healed by being filled with snow or by the freezing of water which may accumulate in them when the bottoms are tightly closed. From the latter result the ice dikes seen on some of the other glaciers.

These crevasses are dangerous pitfalls in the way of the tourist, even when not treacherously hidden by a slight covering of snow. With competent guides and care, however, the less fractured parts of the glacier may be traversed in safety.

At many points on the higher slopes the snow and ice may be seen cascading over the ledges. Here the ice is greatly crevassed and broken and great masses stand ready to fall, especially on warm days. Such cascades, though very attractive, are dangerous to approach. On the slope of Blackfoot Mountain (fig. 13, p. 24), where a great ledge intervenes, the continuity of the cascade is broken for some distance by a cliff of bare rock, above which rises a cliff of ice. Here the ice, which is pushed forward above the cliff, may break off and drop to the glacier below, there to be welded by refreezing into the continuous sheet.

5 *Structure.*—The ice composing a glacier is generally stratified in layers as a result of the conditions of original deposition. This structure may be indicated by more or less definite dirt zones extending in parallel curving lines across the surface of the glaciers. As the layer of snow which accumulates during one winter is gradually thinned or melted away during the succeeding summer, dust and small rock fragments which have fallen upon it become concentrated in a thin but fairly definite layer. This is later buried beneath the clean snows of the following winter. When compacted to glacier ice, therefore, there are apt to be thin layers of somewhat dirty ice alternating with thicker clean layers. In places where the surface of the snow does not become soiled by rock débris, melting may cause the formation of a crust of nearly clear ice which, when buried by later snows, appears as a blue band. The thicker intervening layers appear white because the unfilled air spaces between the ice granules permit reflection of light from the myriad surfaces. The beautiful banded

structure of alternating blue and white ice may be seen in the sides of the crevasses. As the glacier is thinned by melting, these layers outcrop as zones in the frontal slope. They correspond, in a way, to the annular rings in the growth of a tree.

6 *Drainage.*—During the cool nights and early mornings there is little sound of water on a glacier, but as the day warms little rivulets begin to flow on the surface of the ice; where there is much crevassing the water finds its way quickly to the base of the glacier, and there it may be heard rushing down the slope. From the front of the ice there flow rushing streams white with silt from the rock ground fine beneath the glacier, the "gletschermilch" of the Germans. The main or eastern part of Blackfeet Glacier is somewhat less crevassed and more water flows in rivulets upon the ice. These unite to form streams a foot or two in width, but of high velocity, since the surface of the glacier has toward the front a 15° slope. The sharply sinuous channels cut in the ice reach, in places, depths of 20 to 35 feet. At one point a stream was seen plunging down a vertical well, or moulin, to join the subglacial flow. The depth of such a hole might be measured to ascertain the thickness of the ice.

7 *Work of the glacier.*—The work of such a glacier as that being described is manifested in the production of the cirque or amphitheater which it occupies, in the abrasion of the rock floor over which it moves, and in the deposits resulting from the drift which it produces and transports.

The greater part of the rock composing the mountains of the park is stratified in layers, mostly thin, but ranging in thickness from a fraction of an inch to 30 feet or more. The strata are generally broken at frequent intervals by cracks or joints, and water percolating into these crevices expands on freezing and forces the pieces apart. Alternate freezing and thawing breaks up and loosens the fragments ready to be removed. Many fall or are carried down from the cliffs and upper slopes by avalanches of snow. Others beneath and behind the glaciers become frozen in the moving ice and are plucked from their places and slowly carried away. The ice always advances and never retreats, so that as long as the glacier exists, unless it becomes absolutely stagnant, material is continually being removed. A glacier may thus be said to gnaw continually at the slope and eat its way back into the mountain.

Some geologists maintain that the breaking up of the rock and the plucking away of the loosened fragments is particularly facilitated by changes in temperature in the air and the water admitted by the yawning bergschrund which is so often seen in the névé at the back of the glacier. Continued sapping steepens the walls until the great amphitheaters or cirques are produced. The Blackfeet Glacier does not occupy such a deep and symmetrical cirque as is seen at many

other places in the park. It is probable, however, that this is still being extended back into the mountain slope.

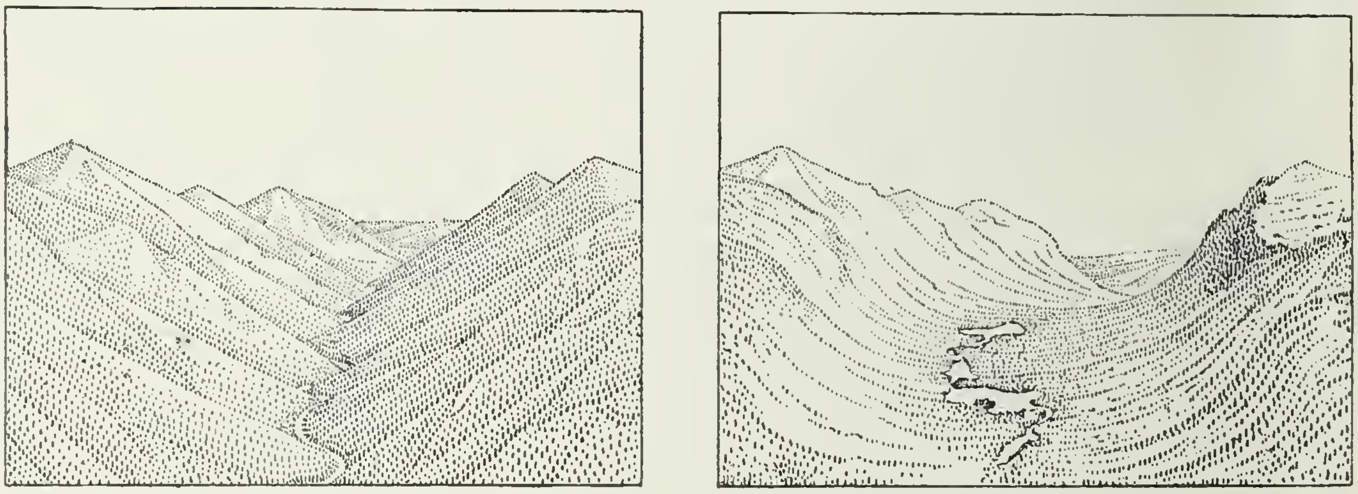
Only a relatively small amount of rock débris falls from the upper mountain slopes onto the Blackfeet Glacier, and there is little or no drift seen embedded in the ice exposed in the sides of the crevasses, neither is any being carried by the surficial streams. Looking into caverns under the ice, one sees here and there pebbles and bowlders at or in the bottom of the ice, and the undersurface is coated with a thin layer of mud, the product of the grinding of the fragments and of the rock bed beneath the glacier. One sees also the smoothed, polished, and striated rock surface extending back beneath the base of the moving ice. A glacial quarry was observed in the upper part of the bared space between the northwest margin of the Blackfeet Glacier and the moraine. Here the ice has evidently plucked loosened blocks from the exposed edges of the strata as quarrymen remove layer from layer in the process called stoping. Many blocks derived in this way are found incorporated in the morainal embankments. Some of the blocks are but little worn, as though transported on the surface of the ice, but most of them are subangular with polished and striated facets, showing the effects of abrasion beneath the glacier. Much of the morainal material is fine rock flour. The whole constitutes a heterogeneous deposit of unassorted glacial till. Sharp morainal embankments border nearly the whole frontal margin of the Blackfeet Glacier (fig. 13, p. 24).

Former extent of the glacier.—The marginal lobes of the main eastern part of this glacier, like the western lobe, are somewhat shrunken from their moraines, an indication that some time ago the ice had a greater extension.

On the slope between Gunsight Camp and the glacier the surface of the limestone is in most places somewhat roughened as a result of etching by solution by the water flowing over it. In places, however, the surface is smooth, polished, and scratched the same as the rock surfaces within the moraines. This indicates that at some time the glacier extended beyond the limits now marked by the moraines. Similar glaciated surfaces are found far down St. Mary Valley, and the valley bottom and lower side slopes carry glacial drift quite to the international boundary, a distance of 38 miles from the divide at Blackfoot Mountain. Such drift extends up the slope east of Lower St. Mary Lake nearly to 5,800 feet above tide; i. e., 1,300 feet above the lake. Drift was also found on the slope of Singleshot Mountain west of Upper St. Mary up to an elevation about 1,200 feet above the lake. Moreover, that part of St. Mary Valley within the mountains has not the sharply cut V-shaped transverse profile of a stream-cut mountain gorge, but has the broadly rounded U-shaped profile typical of a glaciated valley. Tributary to St.

Mary Valley above the lower lake are more than 25 cirques, which formerly contained glaciers. From such evidence it is apparent that the whole St. Mary Valley as far down as the international boundary was once occupied by a great glacier, of which Blackfeet Glacier and 17 other smaller glaciers remain as the only representatives in this part of the park. (See map facing page 32.) The contours of the valley indicate that the great St. Mary Glacier must have had a thickness of 2,000 to 2,500 feet where is now Upper St. Mary Lake.

Glacial modification of St. Mary Valley.—Figure 1, *A* and *B*, which is based on the contours of Swiftcurrent Valley, illustrates the difference between a stream-cut mountain valley and the same valley after it has been subjected to vigorous glaciation. In the paper by Mr. M. R. Campbell on the origin of the scenic features of the park, it is pointed out that the formation of the great mountain valleys was



A. *B.*

FIG. 1.—*A*, SKETCH OF STREAM-CUT VALLEY; *B*, SKETCH OF SAME VALLEY AFTER MODIFICATION BY GLACIATION.

due primarily to the work of streams which cut deeply into the mountain mass. When climatic conditions became such as to result in the vast accumulation of snow great glaciers developed in each of the mountain valleys. As the glaciers gradually extended all of the loose rock débris which had accumulated on the lower part of the slopes and at their feet became frozen into the base of the ice. Partially loosened blocks were also plucked away bodily and moved forward down the valleys. A mass of ice 2,000 feet in thickness exerts a pressure of 56 tons per square foot on the bed upon which it rests. The rock-shod ice thus became in effect an enormous rasp, which scored and polished and wore away all the minor irregularities of the slopes and bottoms of the valleys. Such enormous masses of moving ice do not adjust themselves to the sinuosities and irregularities of the valleys as readily as does water in its liquid state. In consequence of this and of the enormous weight of the moving mass, every opposing ledge and mountain spur were subjected to vigorous abrasion; the valley bottom was broadened and the side slopes were steepened until the whole became a broad open trough.

The attitude of the rock strata and the resistance which they offered to removal as a consequence of differences in hardness or in massiveness of bedding determined in some degree the depths to which the valley was deepened in various parts. Thus a particularly resistant stratum, such as the massive ledge of limestone which crosses St. Mary Valley at the narrows in Upper St. Mary Lake, was not worn away to the same extent as were the softer rocks farther down the valley or the thinner-bedded rocks above. Broader basins were thus developed above and below this ledge, and when the ice melted away these basins were filled with water, forming a lake. The failure to cut as broad a channel through the limestone ledge caused the constriction or narrows in Upper St. Mary Lake. In some of the other valleys, such as Swiftcurrent Valley, a lake was formed above the ledge, but no channel was cut through, so that the escaping waters plunge in a foaming cascade over the obstruction to the valley below. Moraines and other deposits of drift were left on the melting of the great valley glaciers, and in some places lakes, such as Bowman Lake and Quartz Lake, are due, in part at least, to the blocking of the valleys by such accumulations of drift.

HARRISON GLACIER.

One of the interesting trips from Gunsight camp is southwestward up the smooth, snow-covered surface of the upper western part of the Blackfeet Glacier to the crest of the Continental Divide in the notch southeast of Jackson Mountain. Looking westward from this point one gets a magnificent view of the cascading lobes of Harrison Glacier (fig. 2). The main glacier, which lies high in the upper northern part of the great cirque at the head of Harrison Creek, is seven-tenths of a mile wide from east to west and nearly a mile long from north to south. From this a series of ice lobes spill over and cascade down the steep slope to benches in the great cirque wall. Of these the one nearest the observer and the one farthest away appear to extend to well-marked moraines, the one near by does not reach the highest and outermost of the ridges, but ridged drift is spread over the space between the ridge and the ice front. The front of the fourth is some distance back from the end moraine, from which two finely developed laterals extend up the slope. The fifth lobe breaks off at the top of a cliff over which its morainal material is pushed.

SPERRY GLACIER.

General relations.—High up in the upper cirque at the head of Avalanche Basin lies Sperry Glacier[1] (fig. 12, p. 24). This is next in size to Blackfeet Glacier, having a maximum width at the front—i. e., from

[1] In January, 1896, there was published in Appalachia (Vol. VIII, pp. 57–69) an article by Lyman B. Sperry on Avalanche Basin, Montana Rockies, in which he described explorations of this basin made in May and July, 1895, by a party of which he was a member. An effort was made at this time to reach the upper cirque and find the source of the waters which were seen to be milky with glacial silt. It was not, however, until 1896 that Dr. Sperry succeeded in reaching the glacier which now bears his name. (See Glaciers in the Montana Rockies, by L. W. Chaney, jr., Science, new ser., Vol. IV, pp. 761–762, 1896.)

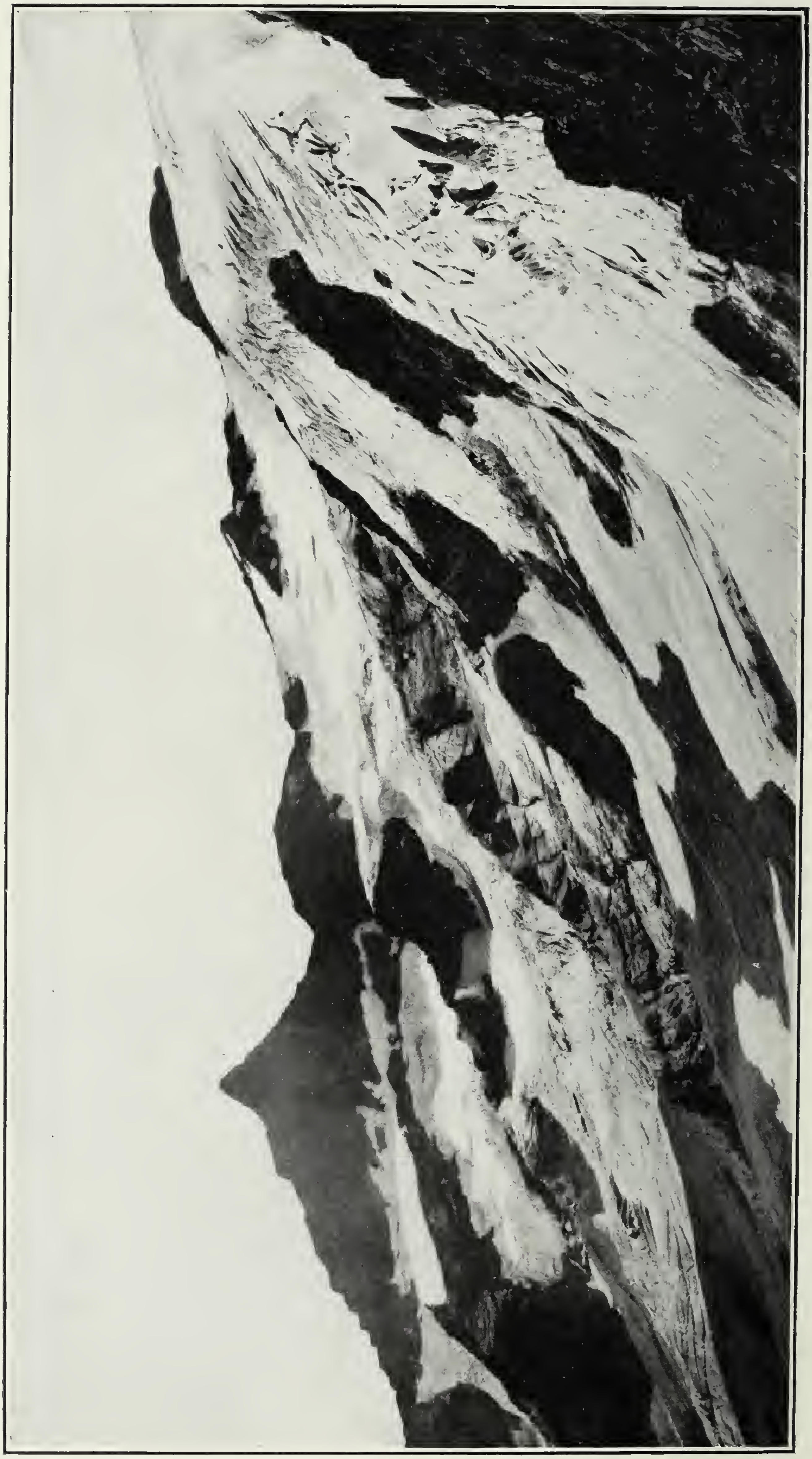


Fig. 2.—Harrison Glacier, showing the cascading frontal lobes.

Photograph by W. C. Alden.

northeast to southwest—of $1\frac{1}{2}$ miles—and a length—i. e., from northwest to southeast—of about 1 mile. Its area is estimated as about 1 square mile. The great cirque at the head of Snyder Creek between Edwards Mountain on the south and Mount Brown on the north was excavated so far back into the mountain mass that the upper part of the divide between Snyder Valley and Avalanche Basin was cut away, leaving a broad notch between Edwards Mountain and the small pyramidal peak known as Little Matterhorn. Through this col some of the water from the eastern part of Sperry Glacier goes to Snyder Creek. A similar notch was also developed between Edwards Mountain and Gunsight Mountain. It is through this latter notch that the trail climbs from the creek at the crossing below

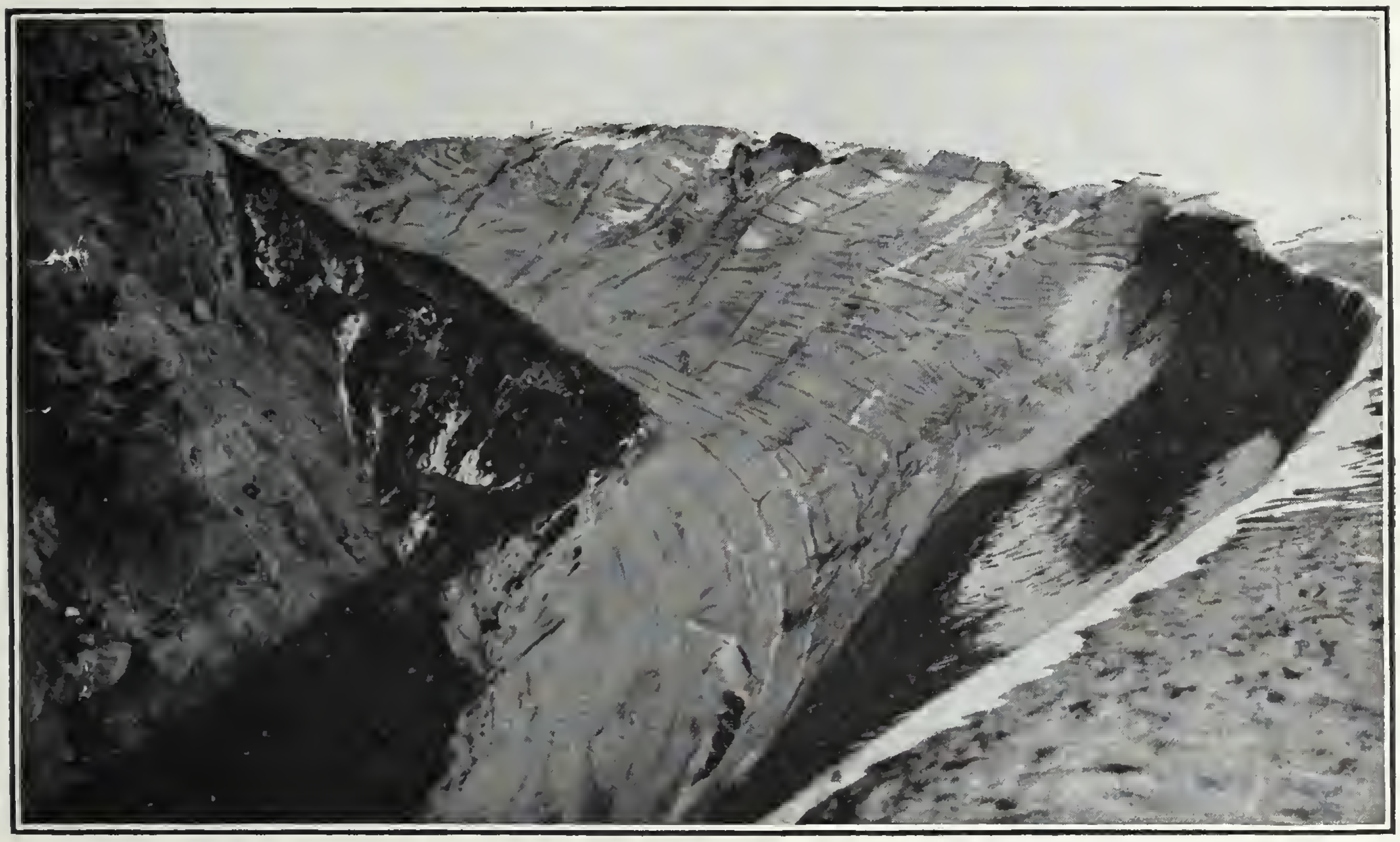


Fig. 3.—Moat at east side of Sperry Glacier, showing stratification in the ice wall on the right.

Photograph by W. C. Alden.

Sperry Camp, about 6,200 feet above tide, to the southwest side of the glacier at 7,700 ± feet above tide.

The surface of the ice is for the most part smooth and not crevassed and may be crossed in any direction. With care one may also descend the slope to the frontal margin. At the southwest side, the front is about 450 feet lower than the top of the iron ladder. It is at and near the front of the ice that the most interesting phenomena are to be observed.

Structure.—In the front slope soiled zones mark the outcropping of the dirty surfaces of successive ice strata, each the residuum of one or more year's snowfall. Other than this the surface of the glacier is almost entirely clean of débris excepting on the lower part of the frontal slopes immediately adjacent to the ice margin where there is a scattering of pebbles and bowlders with a little clay. The stratifi-

cation may also be seen in the sides of the few open crevasses. The best view, however, of the bedded structure of the glacier is to be had where the east side of the glacier rounds a salient of the cirque wall at a point about two-fifths of a mile south-southeast of the front

FIG. 4.—SPERRY GLACIER, BERGSCHRUND ON SLOPE OF EDWARDS MOUNTAIN.

Photograph by W. C. Alden.

of the most easterly marginal lobe of the glacier. On the northwest side of the point of the salient instead of the ice crowding against the rock slope there is a great chasm, or moat (fig. 3), one side of which is formed by the rock wall. The other is a smooth, curving wall of stratified ice, 150 feet or more in height. This moat is probably

due, in part, to the fact that the ice passing the rock salient does not at once spread laterally after passing the point. The lower part of the cliff thus exposed is warmed by the afternoon sun and radiates a certain amount of heat which, melting the ice, tends to prevent its closing up the moat until it has passed on some distance around the point or may even actually enlarge it. The water resulting from the melting escapes laterally beneath the glacier so that the moat, at least when visited by the writer in August, 1913, contained no stream or ponds.

3 *Ice caves and glacial movement.*—In the upper part of the névé on the slope of Edwards Mountain a bergschrund (fig. 4) yawns as the result of the ice moving away from the mountain slope. At several points along the front of the glacier there are small caverns. Instead of breaking down immediately after passing the highest part of a ledge, the ice projects forward as an arch fluted in correspondence with the inequalities of the ledge surface. One such ice cave was seen into which a person could walk a distance of 50 or 60 feet from the entrance, and probably one could proceed an equal distance farther if disposed to crawl on his hands and knees on the wet rock. In these caverns the fact that the ice is really in motion may readily be demonstrated. Markers were placed in the ice walls and upon the ledges, and the distance between the marker in the ice and that on the ledge was carefully measured with the following results:

Movement of ice in ice cave No. 1, at point S. 37° E. of Little Matterhorn.—12.15 p. m., August 15, to 11.15 a. m., August 16; advance of one-fourth inch in 23 hours. 11.30 a. m., August 16, to 10.25 a. m., August 17; advance of one-half inch in 24 hours. 10.30 a. m., August 17, to 11.15 a. m., August 17, advance of one-eighth inch in 45 minutes; 11.15 a. m to 4 p. m., advance of one-eighth inch in 4¾ hours.

Movement of ice in ice cave No. 2 at point S. 43° E. of Little Matterhorn.—Noon, August 16, to noon, August 17, advance of one-half inch in 24 hours.

Movement of ice in ice cave No. 3, west side of middle ice lobe, at point S. 87° E. of Little Matterhorn.—1.15 p. m., August 16, to 1.15 p. m., August 17, advance of three-fourths inch in 24 hours.

Movement of ice in ice cave No. 4 at west side of eastern ice lobe at point S. 45° E. of Heavens Peak.—2.30 p. m., August 16, to 2.30 p. m., August 17, an advance of about one-half to three-fourths inch in 24 hours; markers loosened by melting.

The measurements have not been continued over a sufficiently long period to warrant basing upon them an estimate of the average daily or total yearly advance. The measurements made in cave No. 1 show the variations in the rate of motion due to difference in temperature. On the first day, August 15, when the weather was cold and blustering, with some snow falling, an advance of but one-fourth inch was noted. During the following 24 hours the weather became bright and warm, there was much melting of the ice, and the advance noted then was one-half inch.

4 *Moraines.*—The front of the glacier is bordered by well-marked terminal moraines. These are sharp, narrow, and uneven-crested embankments 20 to 50 feet in height, composed of intermingled clay,

or rock flour, pebbles, and bowlders. Generally there is an interval of a few rods between the ice and the main ridges, showing that the glacial margin has retreated somewhat since the formation of the moraine. The foot of the glacier, for the most part, rests on nearly bare rock, but in one place it appears to lie on top of a morainal accumulation nearly 50 feet in height (fig. 5). Here one sees the moraine in process of construction. It is possible that the drift here merely covers the margin of the glacier so that the core of the ridge is of ice.

The southwest half of the glacier is underlain by banded red and white quartzite and argillite, while the floor of the northeast half of the cirque is composed of the grayish to buff limestone. As a result the southwest half of the terminal moraine is composed principally of

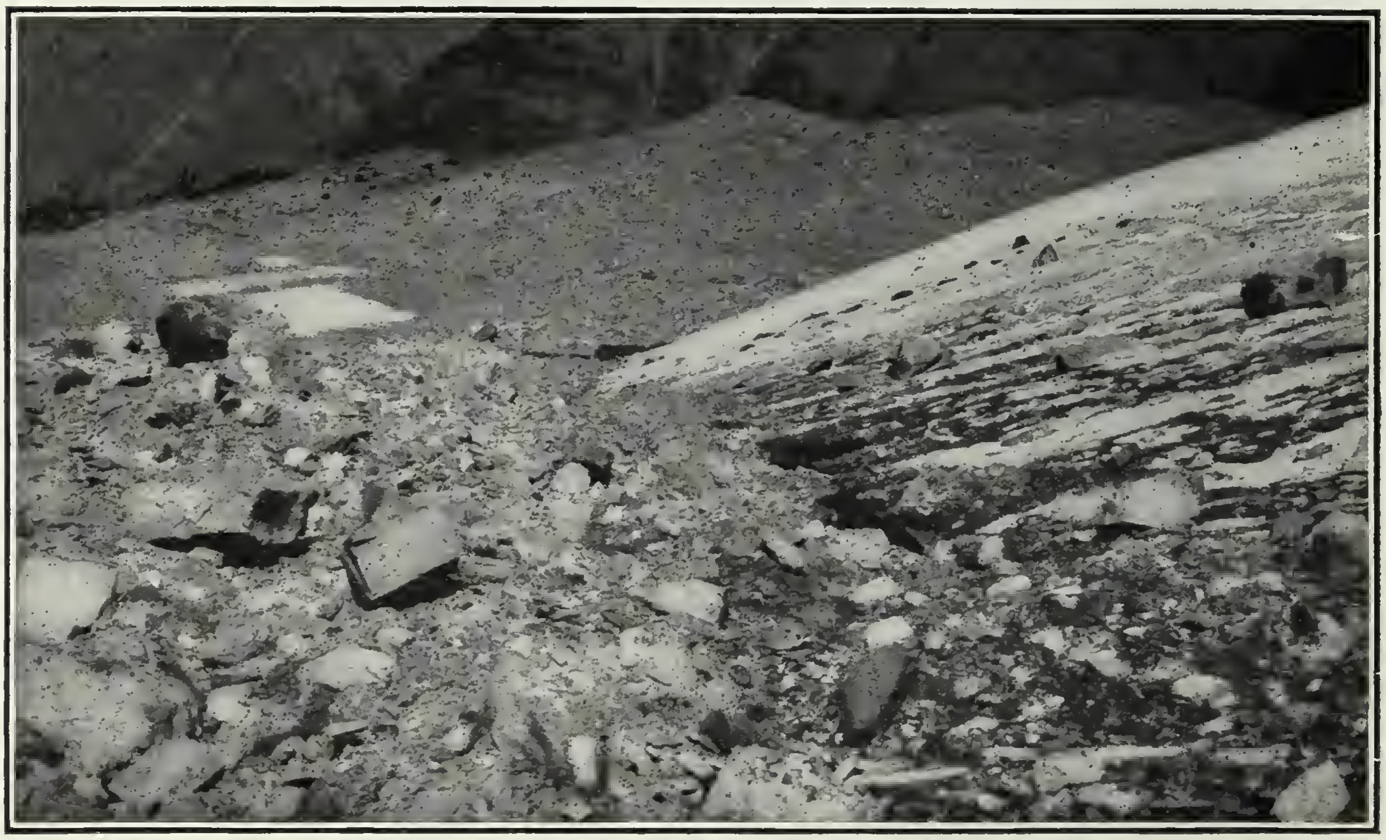


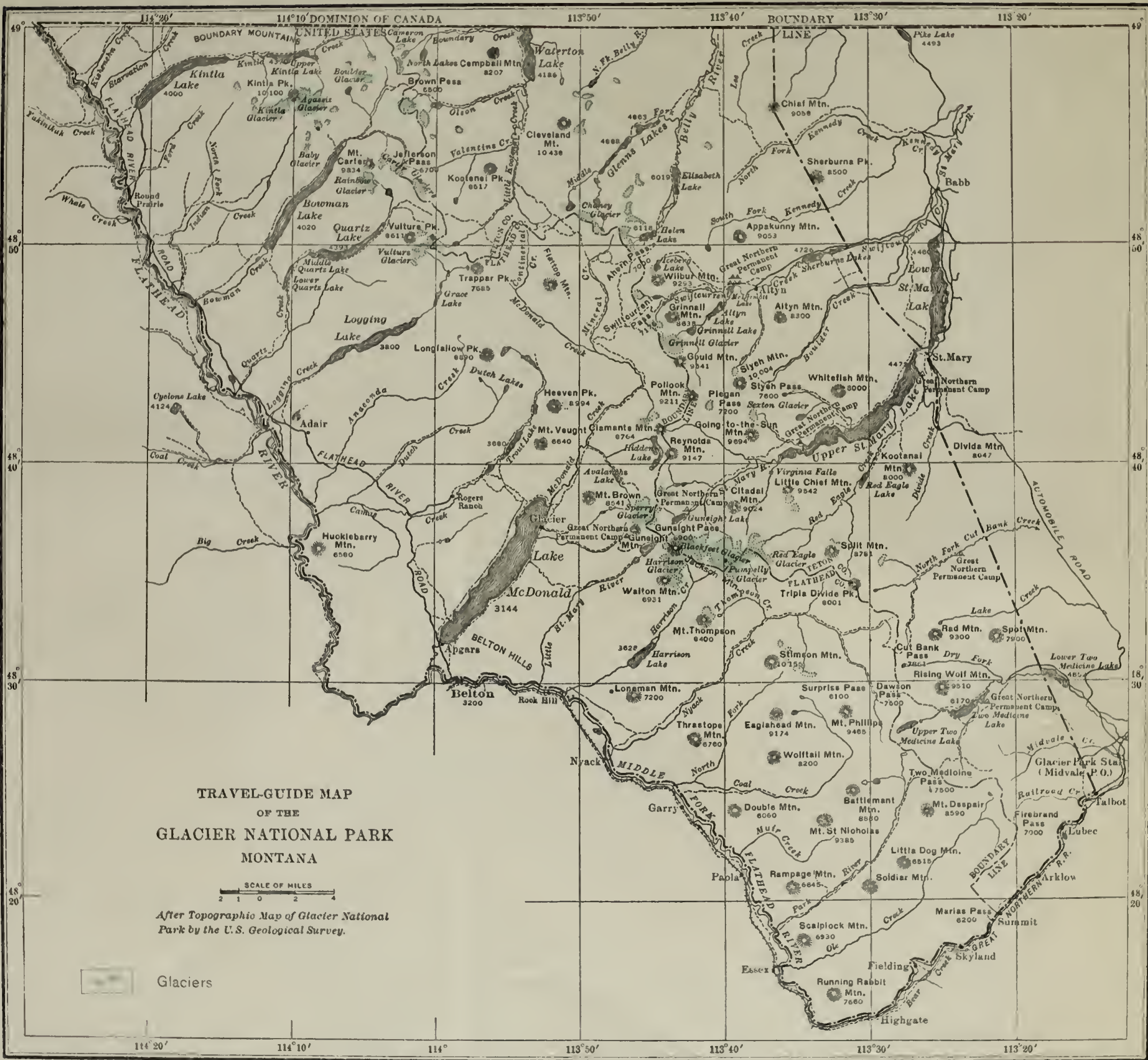
Fig. 5.—Moraine at front of Sperry Glacier.

Photograph by W. C. Alden.

maroon-red argillite and quartzite, and the water in the brooks and morainal ponds is reddish from the silt held in suspension. The northeast half of the moraine, on the contrary, is composed mostly of grayish limestone, and the water of the ponds and streams issuing here is white, the typical "gletschermilch."

At two places marginal lobes of the ice project forward in trough-like depressions in the rock floor of the cirque. Where these ice-tongues occur the moraine bends sharply and extends parallel to the sides of the lobes as lateral moraines. These laterals are connected in a large loop about the end of each ice lobe.

A short distance outside the inner morainal belt is one of earlier formation disposed in loops indicating that the ice margin was formerly somewhat more lobate than at present. This outer moraine is subdued in contour, the irregularities of crest and slope having been


TRAVEL-GUIDE MAP
OF THE
GLACIER NATIONAL PARK
MONTANA
SCALE OF MILES
After Topographic Map of Glacier National Park by the U.S. Geological Survey.
Glaciers
DOMINION OF CANADA
UNITED STATES
BOUNDARY LINE
Kintla Lake
Bowman Lake
Logging Lake
Lake McDonald
Upper St. Mary Lake
Lower St. Mary Lake
Waterton Lake
Belton
Glacier Park Sta. (Midvale P.O.)

partially washed away, and is covered in part by a scanty growth of dwarfed trees.

5 *Rock scoring and plucking.*—In the ice caverns the observer gets an excellent idea of the abrasive work done by the glacier. The surface

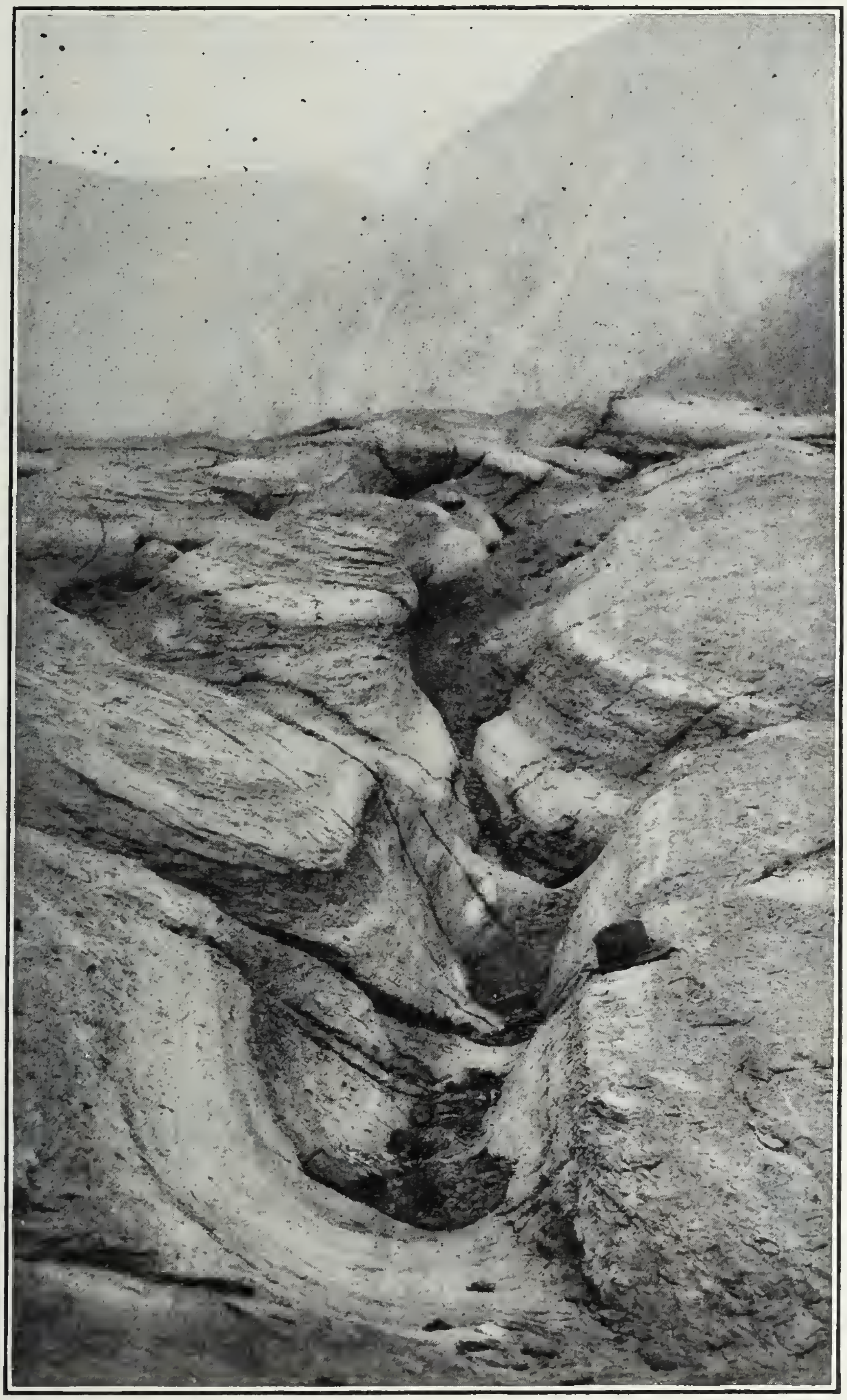


FIG. 6.—GLACIATED GROOVE NEAR FRONT OF SPERRY GLACIER.

Photograph by W. C. Alden.

of the bed rock is beautifully smoothed, polished, and striated. This surface is seen to extend back under the moving ice whose undersurface is plastered with a thin coating of wet mud or rock flour, and set with fragments of rock. This is the abrasive material with which the work is done. There seems to be no considerable amount of

gravel or rock fragments in the base of the ice, as removal of the subsurficial coating shows clear, clean ice above. Here may be seen how the ice, melting under pressure against inequalities of the rock surface, is fluted with grooves corresponding to those irregularities, while at the same time all the small projections are being worn away.

Not only does the surface of the rock floor of the cirque within the moraines show the effects of glaciation, but between the outer moraine and the lip of the cirque, below which the great cliff drops to form the head of Avalanche Basin, the rock is smoothed, polished, striated, and grooved in a remarkable manner. In places the ice has been forced along more or less tortuous grooves, which were probably first worn by water running beneath the ice (fig. 6).

The method of glacial quarrying known as plucking is also well illustrated. At one place east of Little Matterhorn the striated floor is cut by a vertical northeast-southwest joint face. Beyond this a lower level was in process of being developed by stoping when the ice was melted away. Some great blocks of rock 10 by 15 by 20 feet in size have been loosened along the joints and moved distances ranging from a few inches to several feet. Others have been moved 50 to 100 yards or more and left stranded between the quarry face and the lip of the upper cirque. Still others, doubtless, were forced on over the cliff to be dashed in fragments on the ledges below. At one point the opposed faces of a joint, now 3 to 5 feet apart, are striated in a direction transverse to that of the striæ of the main ice movement on the floor above as though the basal ice had squeezed laterally into the crack and gradually forced the block on the northeast away from its original position. One joint but a few feet back from the crest of the cliff at the head of Avalanche Basin has been broadened several feet to a considerable depth. Had the disrupting action continued but a little farther a great mass of the upper part of the cliff would have been tipped over into the great cirque below. It is largely by such processes of glacial plucking or stoping that the great cirques have been excavated. It seems probable that only a subordinate amount of material was removed by abrasion beneath the great rasp formed by the rock-shod ice.

Former extent of the glacier.—The relations are such that there can be no doubt that in comparatively recent time, geologically speaking, though thousands of years ago, Sperry Glacier not only occupied the whole of the upper cirque but filled Avalanche Basin and was confluent with a great glacier in the canyon of McDonald Creek (see map facing p. 32).

At its southwestern end the terminal moraine is near the crest of the cliff at the head of Snyder Creek. Some of the water from the western part of the glacier flows over this cliff. The trend of the striæ outside the moraine also indicates that some of the ice formerly passed through the gap between Edwards Mountain and Little Matter-

horn and joined a glacier in Snyder Creek Valley. It is also probable that some of the ice went through the gaps between Edwards Mountain and Gunsight Mountain to a glacier in Sprague Creek Valley.

All over the rock shelf on which stands Sperry Camp and on the ledges along the trail to Sperry Glacier there is a fine exhibition of the polishing and striating action of the glacier which formerly occupied the valley. Striæ on some vertical faces beside the trail slope steeply, in places nearly or quite vertically, showing how the ice descended from ledge to ledge.

SWIFTCURRENT GLACIERS.

Grinnell Glacier.—The largest of the glaciers at the heads of tributaries of Swiftcurrent Valley is the Grinnell Glacier, so named in honor of Mr. George B. Grinnell, one of the first to explore these mountains. This occupies the upper cirque on the north side of Gould Mountain. From Sherburne Lakes, 10 miles distant, the white and glistening glacier may be seen nestling at the foot of the Garden Wall in the cirque between Gould and Grinnell Mountains. While not so readily accessible as some of the other glaciers this one can be reached from Many-Glacier Camp by going up Cataract Creek trail along the west shore of McDermott Lake and then climbing up and along the south slope of Grinnell Mountain (figs. 7 and 8), or one may get a fine view of it from above by a climb from Granite Park to a notch in the Garden Wall.

This glacier has a width from northwest to southeast of about 1½ miles and a length from southwest to northeast of about 1 mile. Its area is a little over 1 square mile. It consists of a névé-covered upper part, lying on an upper bench in the western part of the cirque, and the main glacier, whose lowest point is not far from the crest of the cliff which rises abruptly nearly 1,000 feet from the valley floor above Grinnell Lake. Through most of its lateral extent the upper mass of ice ends at the crest of the bare rock ledge below the upper bench. South of this, however, the ice cascades over the ledge with a much crevassed surface to the main glacier below. From the encircling cliffs the ice flow converges toward the lowest point in the lip of the cirque. A large part of the surface is crevassed, showing that the ice is moving down over an uneven bed, and nearly the whole surface is banded with the soiled zones which mark the outcropping of the ice strata. A morainal embankment, consisting of narrow sharp-crested ridges of drift 30 to 100 feet in height, closely borders the ice margin on the east and north. (Figs. 7, 8, and 9.) This is in part lateral and in part a terminal moraine.

In a little niche at the side of a deep notch in the crest of the Garden Wall back of Gould Mountain, a thousand feet or more above the main glacier, is a fine example of a cliff glacier (fig. 8). This glacier is short and relatively thick. From the crest of the rock cliff its

nearly vertical face of glistening stratified ice rises 100 feet or more to the smoothly rounded, snow-covered crest (fig. 10).

On the north side of Grinnell Mountain lies another small glacier on a rock shelf at the top of a 1,500-foot cliff. This is in view of tourists

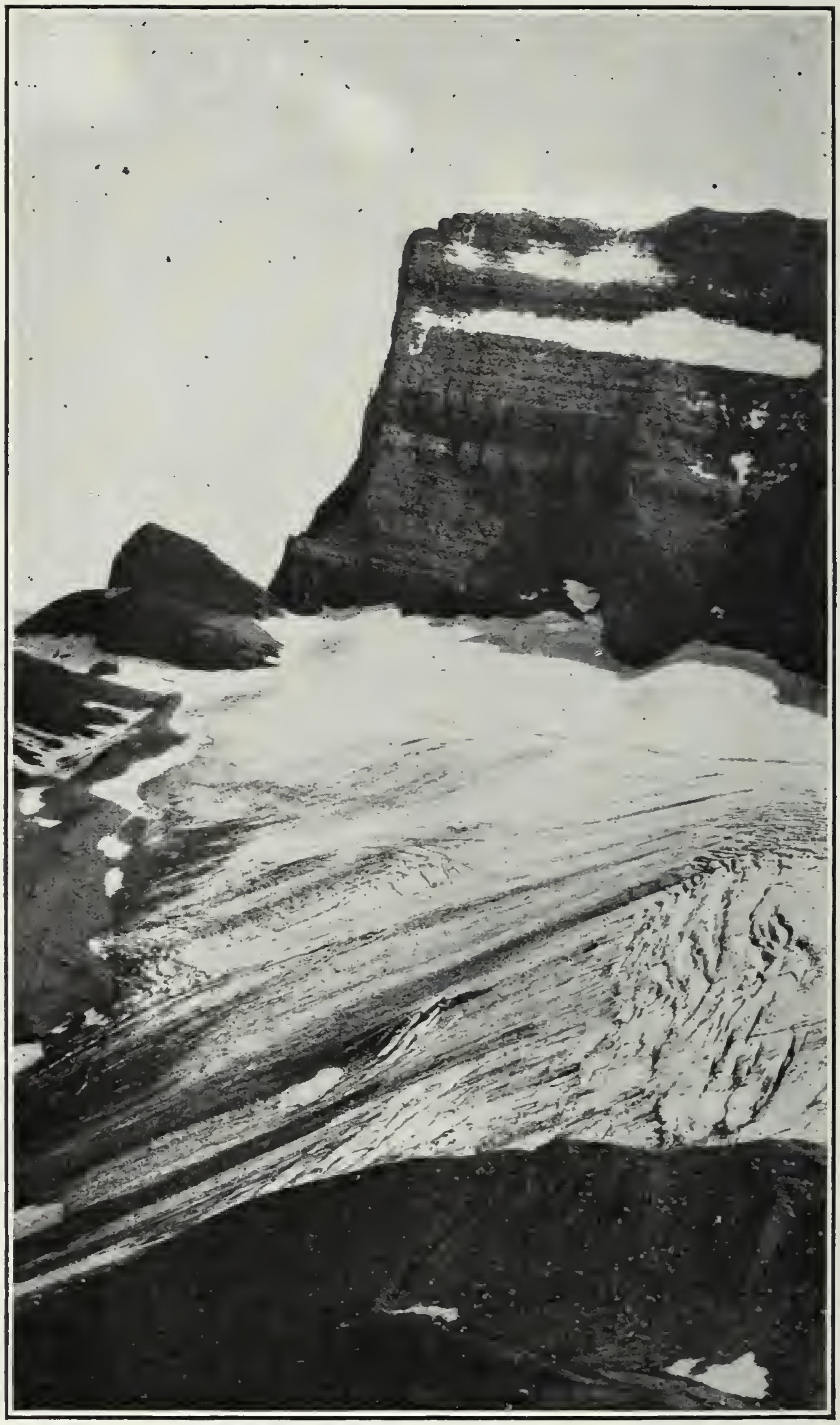


FIG. 7.—GOULD MOUNTAIN AND GRINNELL GLACIER.

Morainal ridge at left and in foreground.

Photograph by T. W. Stanton.

traversing the trail to Swiftcurrent Pass. The ice, which is much crevassed, extends to the crest of the cliff in places and dumps some of its morainal drift into the abyss below.

In the next cirque north of Swiftcurrent Pass there is a notable development of steps or benches due to the stoping action in cirque

formation being carried on at several different levels. These are good examples of steps in a so-called "glacial staircase." There are two

Fig. 8.—Grinnell Glacier, upper part, crest of moraine in foreground.
Gem Glacier above at left.
Photograph by T. W. Stanton.

Fig. 9.—Moraine of Grinnell Glacier.
Piegan Mountain in background.
Photograph by T. W. Stanton.

of these benches in the upper part of the cirque, and on these lie four distinct little glaciers (fig. 11).

Iceberg Lake and Glacier.—The charm of the view at the head of the North Fork of Swiftcurrent Creek lies in the combination of the 3,000-foot, vertical, encircling wall of the amphitheater, the small glacier lying at its base, the beautiful little lake of deepest blue, and the daz-

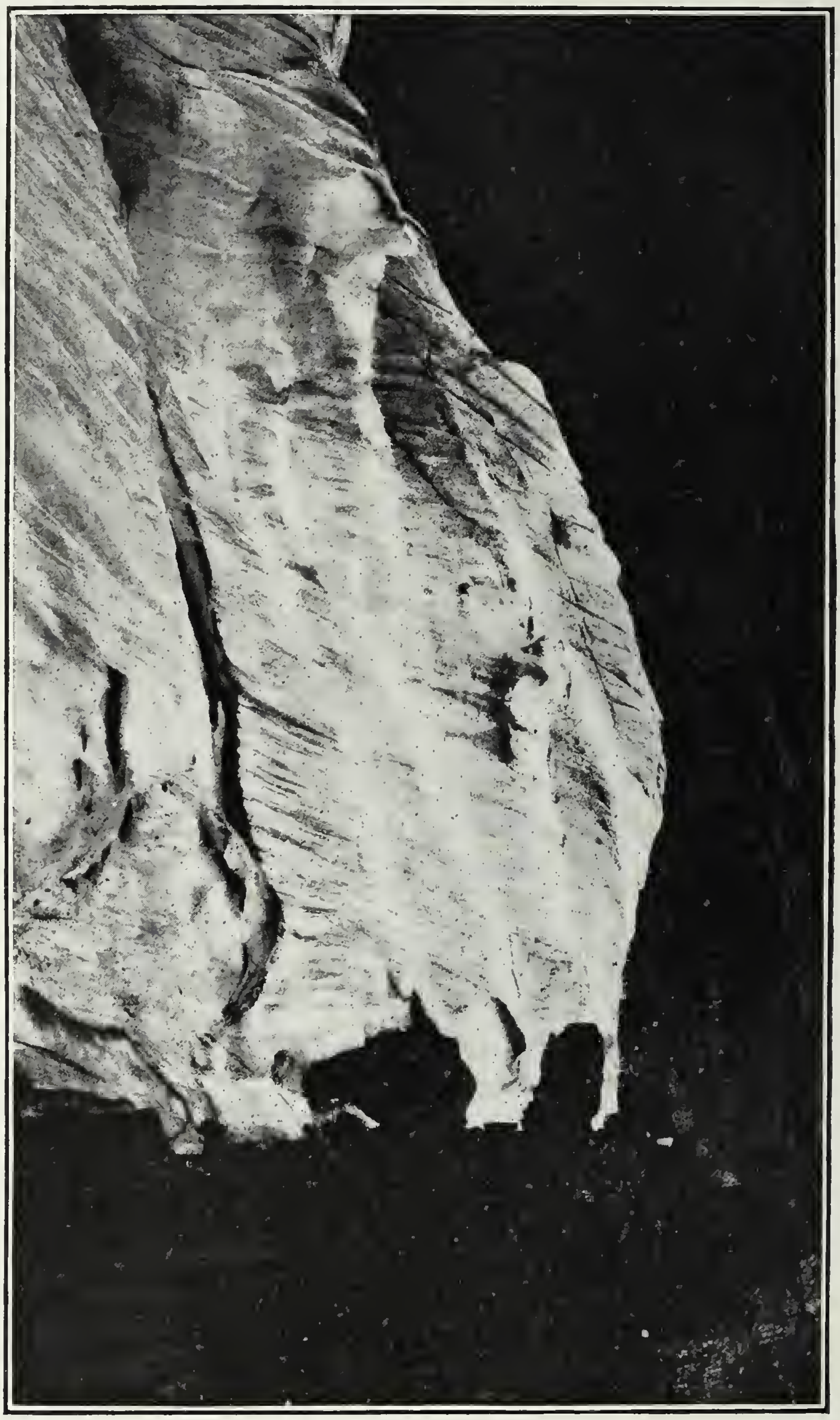


FIG. 10.—FRONT OF GEM GLACIER; ON THE GARDEN WALL ABOVE GRINNELL GLACIER.

Photograph by T. W. Stanton.

zling whiteness of the small icebergs usually floating in the lake (fig. 14). With these masses of glacier ice there are usually cakes of lake ice floating even in August. Along the east shore of the lake is an "ice rampart" of bowlders probably pushed up by the forward crowding of the ice when the lake is frozen over in the winter.

Crossing the shallow outlet stream one finds a way along the talus slope and over the ledge around the north shore of the lake. There is a considerable accumulation of angular and unworn rock fragments piled on the ice at the north side. This has evidently fallen from the cliffs and has been handled by the glacier only enough to pile up sharp morainal ridges 30 to 40 feet in height. Crossing these one reaches

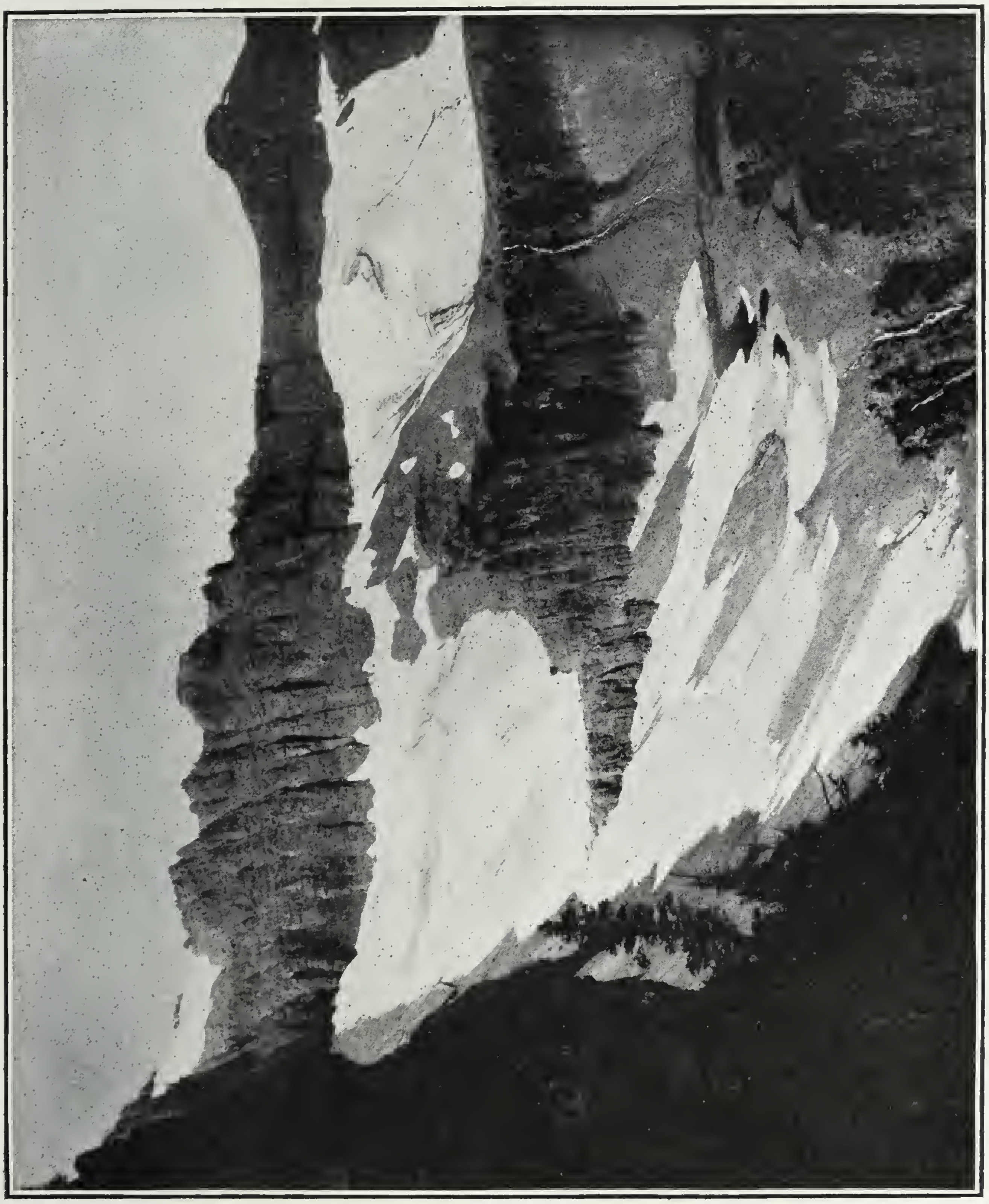


Fig. 11.—Glaciers on steps of a "glacial staircase" in cirque north of Swiftcurrent Pass.

Photograph by W. C. Alden.

the main part of the glacier (fig. 15), upon which there is also a sprinkling of rock fragments. Toward the front the ice is broken by crevasses (fig. 16), and much of this drift must fall into these yawning cracks, and thus reach the base of the ice, there to be ground and polished beneath the moving glacier and pushed forward into the lake. In the ice walls of these crevasses the banded, stratified structure of the ice is well displayed. In that part south of the morainal ridge where seen by the writer, the banding is longitudinal, i. e., parallel to

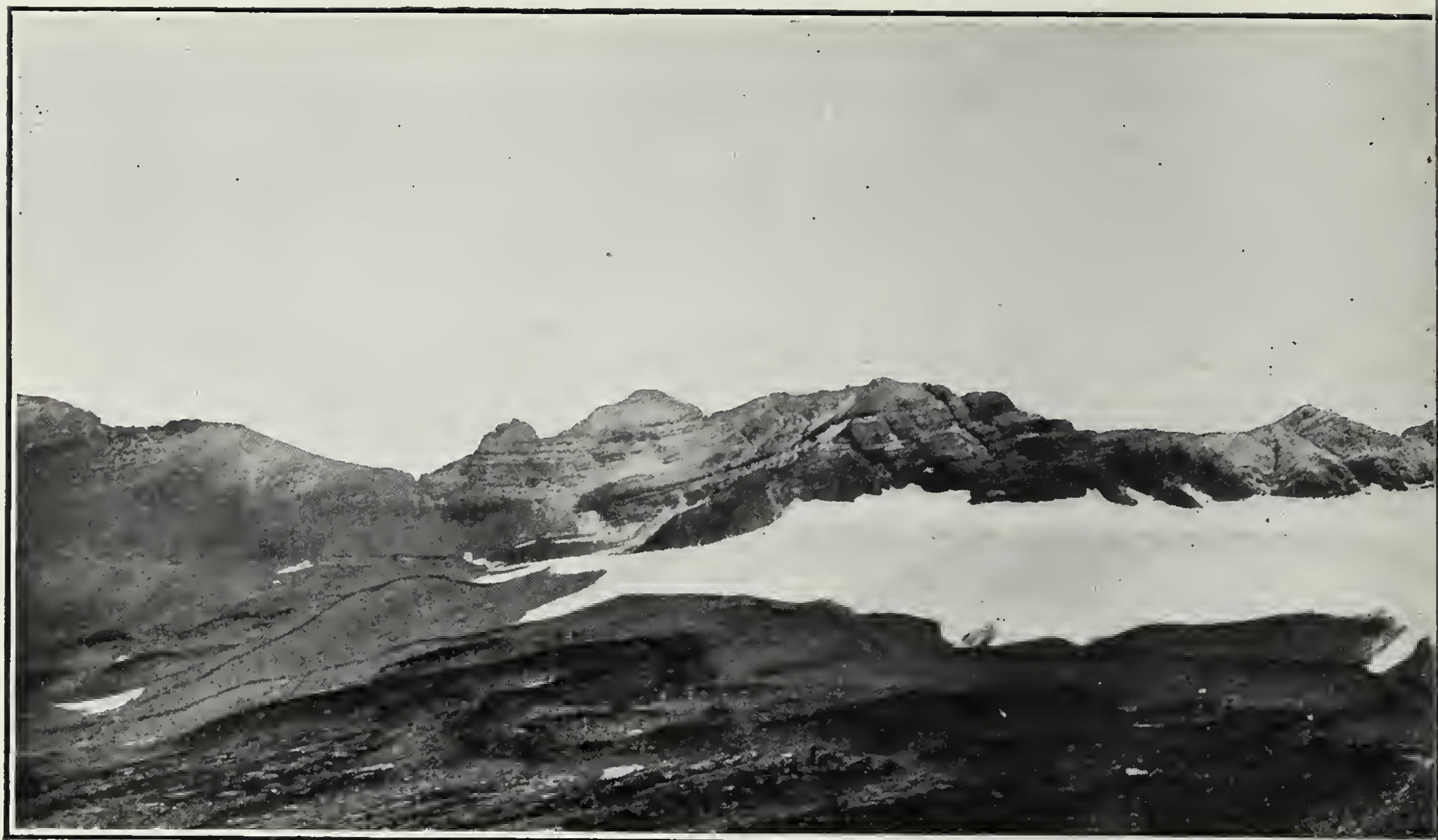


FIG. 12.—SPERRY GLACIER FROM LITTLE MA

Photograp

FIG. 13.—BLACKFEET GLACIER, EASTERN PART, BLACK

Photograph

RHORN, GUNSIGHT MOUNTAIN IN BACKGROUND.
W. C. Alden.

T MOUNTAIN AND JACKSON MOUNTAIN IN BACKGROUND.
W. C. Alden.

the direction of the ice flow, and it is seen in the sides of the crevasses to dip southward at an angle of from 30° to 45°. In the front of the glacier this dip is seen to decrease southward and become nearly horizontal or slightly undulating and to extend thus across the glacier.

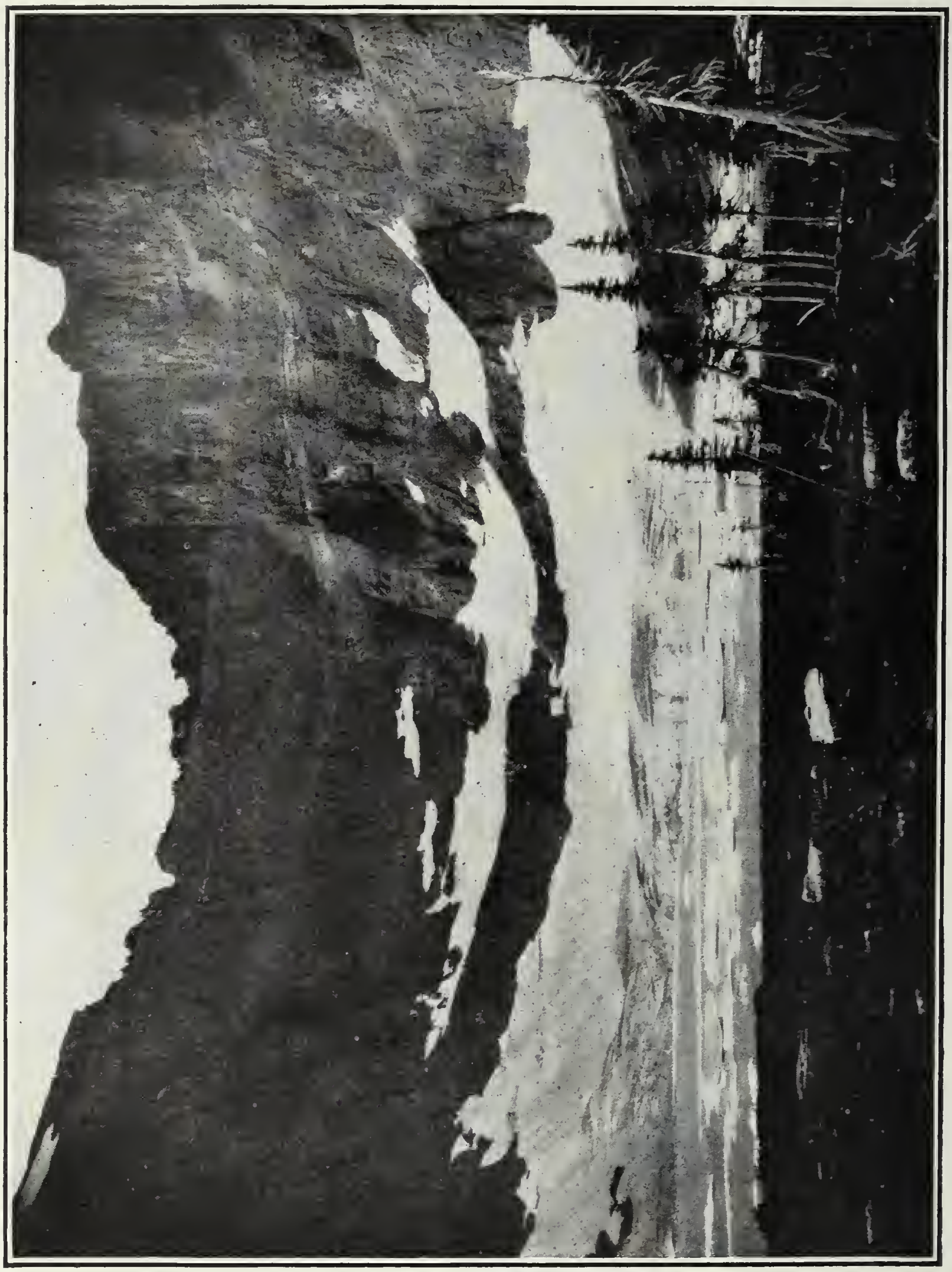


Fig. 14.—Iceberg Lake and Glacier.
Photograph by M. R. Campbell.

Toward the south side the banding appears to curve again downward at a high angle which decreases again toward the south wall.

The front of the glacier is now nearly a mile back from the crest of the cliff over which the trail climbs to the upper cirque. Striations on the rock ledges east of the lake show that at some former time the ice extended across and beyond the rock basin in which the lake now lies. Loosened and partially removed blocks of rock at and near the cliff between the lower valley and the upper cirque suggest the method

FIG. 15.—FRONT OF GLACIER AT ICEBERG LAKE.

Photograph by W. C. Alden.

FIG. 16.—GLACIER AT ICEBERG LAKE SHOWING CREVASSES AND ROCK DÉBRIS ON THE ICE.

Photograph by W. C. Alden.

Fig. 17.—Swiftcurrent Valley from the Pass, showing steepened slopes and smoothly rounded U-shaped profile due to glaciation.

Photograph by M. R. Campbell.

by which the more extended moving ice was stoping back the cliff face when the melting of the ice ended the operation.

Canyon Creek Glacier.—Above the beautiful lake at the head of Canyon Creek one may cross the alluvial fan and climb the steep slope of the moraine which is being built up by a small glacier. The glacier, which is almost covered with rock fragments fallen from the great encircling cirque wall, is considerably crevassed as though crowding forward over the lip of the cirque. A still higher bench in the back of the cirque holds a small crevassed glacier and high up upon the west side in a niche above a projecting ledge is a third.

Former extent of the ice.—The broadly rounded, U-shaped profiles of the valley (fig. 17), the oversteepened side slopes with small amount of talus, the glaciated rock ledges, and deposits of glacial drift, together with other general relations, indicate that during the last, or Wisconsin, stage of the glacial period, Swiftcurrent Valley and all its tributaries were occupied by a great glacier which was in turn tributary to a former glacier which may be called the St. Mary glacier (see map facing page 32). The small existing glaciers described above are the diminutive remnants of this great stream of ice. The height to which Swiftcurrent Valley was filled by this glacier is not definitely known, but it probably reached 2,000 or 2,500 feet. High upon the mountain slope to the north, about 1,600 feet above the outlet of McDermott Lake, the writer observed rock ledges which had been polished and striated by ice moving eastward down the valley. Similar striæ were also seen on the northwest slope of Allen Mountain at about the same height above the lake. About 5 miles farther east where this glacier joined the trunk of the former St. Mary glacier the ice must have been at least 1,000 feet thick, judging from the elevations of the moraine which incloses Duck Lake, 3 to 6 miles east of the village of Babb.

BELLY RIVER GLACIERS.

Glaciers at Ahern Pass.—From Granite Park a trail leads northward to Ahern Pass. By this route one may cross the divide and descend Belly River Valley. From the pass down to the upper lake the trail is passable for pedestrians using caution but is not in condition for saddle or pack animals. August 22, 1890, Lieut. George P. Ahern[1] led a party, consisting of a detachment of soldiers from the Twenty-fifth Infantry, Mr. G. E. Culver and two prospectors, with packers, Indian guides, and a pack train, up Belly River Valley and across the pass which bears his name.

One interesting feature of this trail is that after passing the divide it leads down across the upper part of the sloping surface of a small glacier and then passes out along the steep valley side, which is cov-

[1] Notes on a little known region in northwestern Montana, by G. E. Culver, Trans. Wis. Acad. Sci., vol. 8, pp. 185–205, 1888–91.

ered with loose sliding rock excepting where there are precipitous rock ledges. The surface of the small glacier descends steeply about 500 feet to the crest of a cliff which drops down thence 1,000 feet to the head of the valley below (fig. 18). The angle of slope of the ice for several hundred feet above its foot is about 45°, and this steep slope is in part scored by open crevasses. It is not a suitable place for coasting. This glacier occupies a niche in the upper south wall of the great cirque just below the pass. The main head wall of the amphitheater is one of the most imposing in the park. The peak at its crest north of the pass stands nearly 3,600 feet above the upper lake. Of this the upper 2,500 feet stands almost vertical. Below this some small glaciers, with their névé banked against the base of the cliff, spread out slightly on the rock bench above the lake. These

Fig. 18.—Glacier at Ahern Pass.

Photograph by T. W. Stanton.

are bordered by comparatively large moraines. One of these as seen from above surrounds the narrow end of the glaciers as a sharp V, like the nose of a snow plow (fig. 19.) The ice appears to be thinned as the ridge stands up abruptly from its débris-covered surface. A short distance outside this is an earlier moraine covered with vegetation and encircling a pond of water.

At the top of the vertical northwest wall of the cirque is another glacier about 2,600 feet above the lake. This lies 500 feet or more above the level of Ahern Pass so that only its front edge can be seen from that point. To one looking down upon it from the mountain top above it appears as a considerable mass of ice with a width from north to south of seven-tenths of a mile and a length from northwest to southeast of one-half mile. The frontal margin is pushed forward

quite to the crest of the cliff and in places appears to overhang so that the drift as it is thrust forward, and doubtless some of the ice also, falls over the precipice and the streams hang on the dark rock wall like silvery threads.

Chaney Glacier.—From a camp on Flattop comparatively easy access to the glaciers at the head of Middle Fork of Belly River is

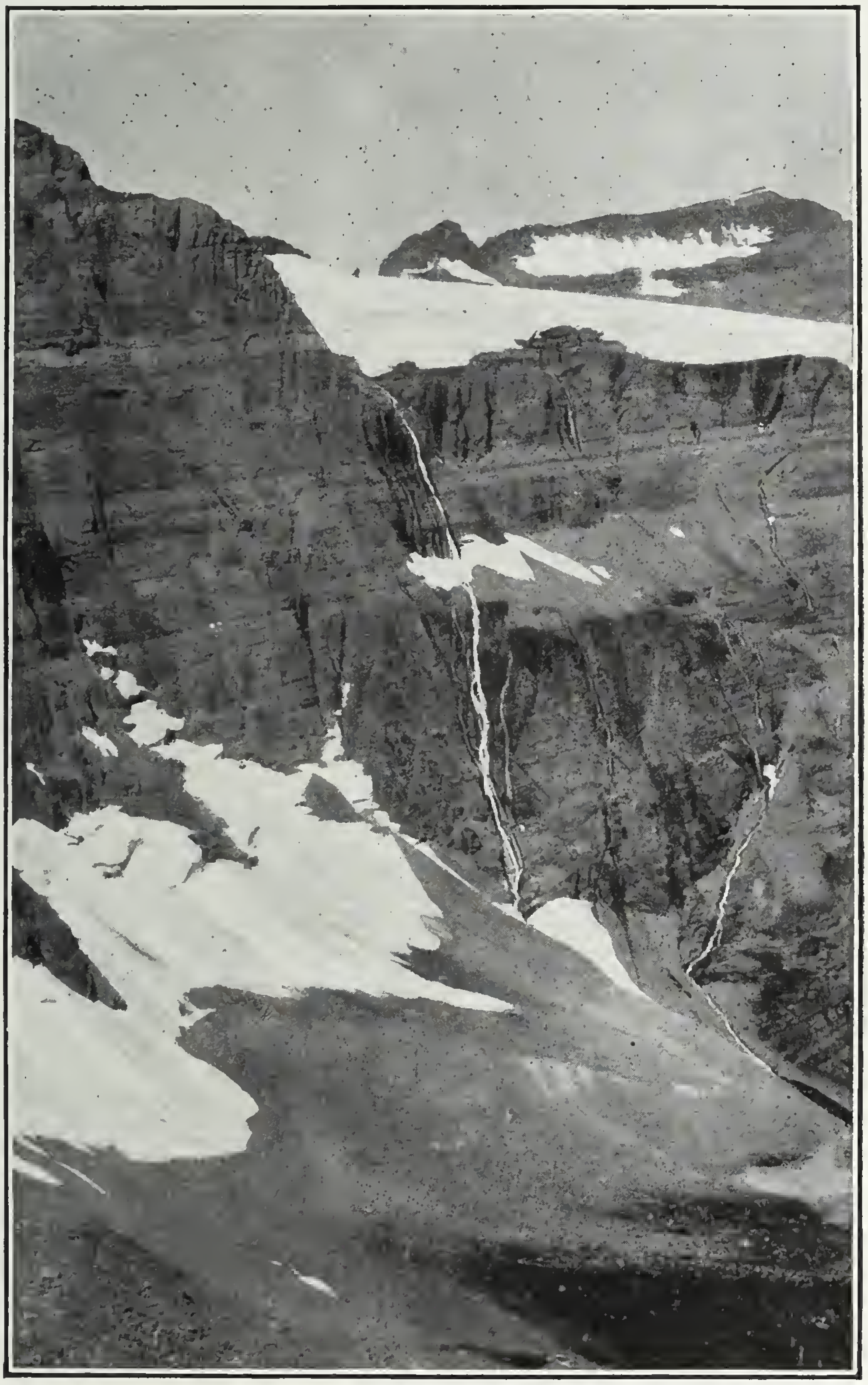


FIG. 19.—GLACIERS AND MORAINES NEAR AHERN PASS.

Photograph by W. C. Alden.

gained by climbing to the notch in the crest of the mountain wall at the head of Mineral Creek. All five of these glaciers occupy scallops in the great upper cirque, above the tops of the cliffs against which head the main floors of the two branches of the Middle Fork.

From the notch, which is at about 7,950 feet above sea level, one sees Chaney Glacier spread out at his feet. This glacier was named

in honor of Prof. L. W. Chaney, jr.,[1] of Carleton College, of Northfield, Minn., who visited it in 1895.

Chaney Glacier (fig. 20) has a width from northwest to southeast of about 1 mile. From its upper edge, about 15 or 20 feet below the

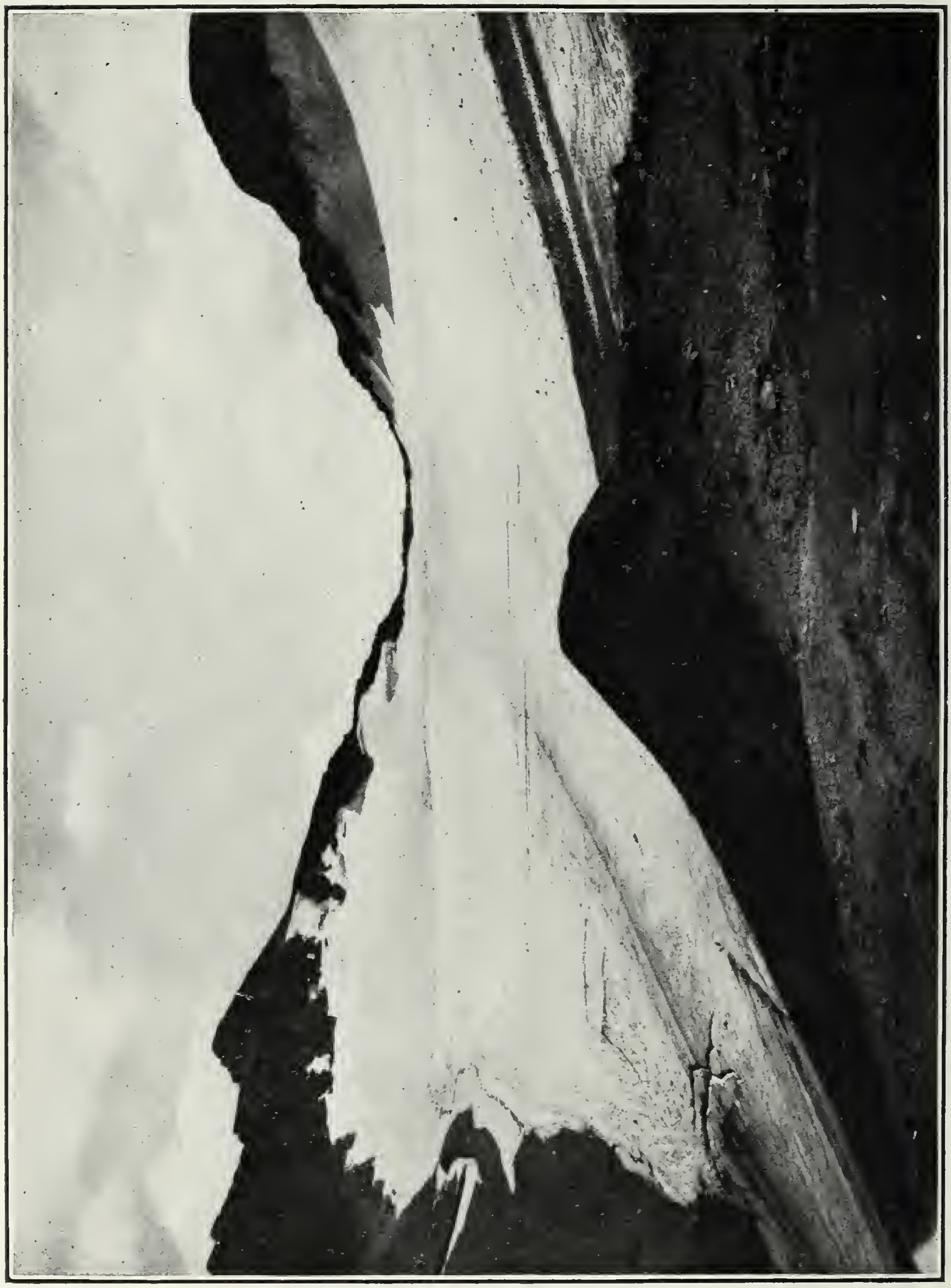
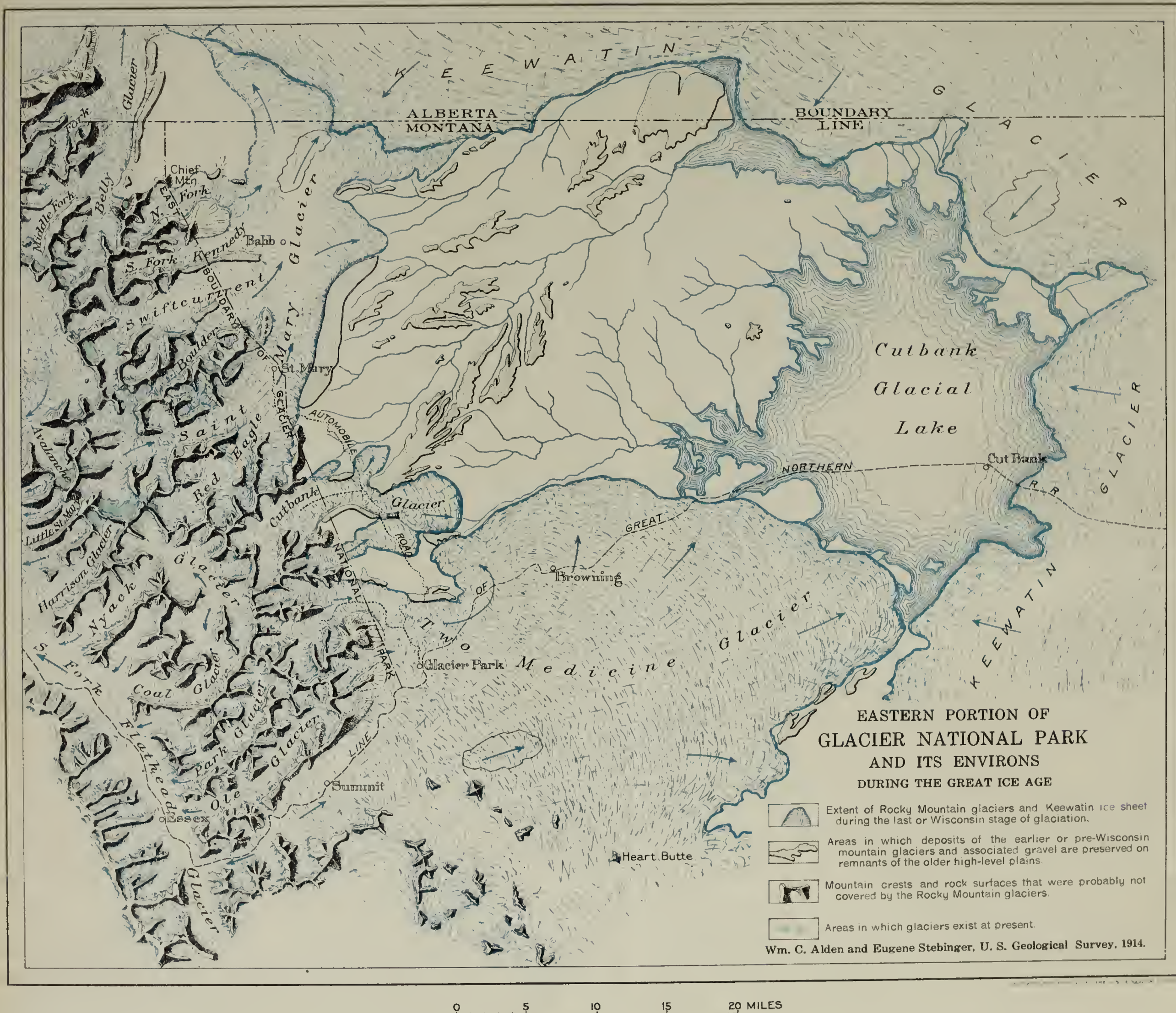


Fig. 20.—Chaney Glacier.
Terminal moraine in foreground, medial moraine at right.
Photograph by M. R. Campbell.

notch in the divide, the smooth surface of the ice slopes northward. At the top the slope is gentle, but toward the front it is steeper, descending about 1,200 feet in a distance of one-half mile. At the north side of the eastern part of the glacier the ice extends as a narrowing tongue down into a notch in the lip of the upper cirque.

[1] Appalachia, Vol. VIII, 1896–1898.


KEEWATIN
ALBERTA
MONTANA
BOUNDARY LINE
GLACIER
Chief Mtn
Belly
Middle Fork
N. Fork
EAST
Babb
S. Fork Kennedy
Swiftcurrent
Boulder
BOUNDARY OF GLACIER
St. Mary
Mary Glacier
AUTOMOBILE
ROAD
Saint
Red Eagle
Avalanche
Cutbank
Glacier
Cutbank Glacial Lake
Cut Bank
NORTHERN
GREAT
R. R.
Little St Mary
Harrison Glacier
Nyack
Glacier
NATIONAL
PARK
Browning
Two Medicine Glacier
Glacier Park
S. Fork
Coal Glacier
Flathead
Park Glacier
Ole Glacier
LINE
Summit
Essex
Glacier
Heart Butte
KEEWATIN GLACIER
EASTERN PORTION OF
GLACIER NATIONAL PARK
AND ITS ENVIRONS
DURING THE GREAT ICE AGE
Extent of Rocky Mountain glaciers and Keewatin ice sheet during the last or Wisconsin stage of glaciation.
Areas in which deposits of the earlier or pre-Wisconsin mountain glaciers and associated gravel are preserved on remnants of the older high-level plains.
Mountain crests and rock surfaces that were probably not covered by the Rocky Mountain glaciers.
Areas in which glaciers exist at present.
Wm. C. Alden and Eugene Stebinger, U. S. Geological Survey, 1914.
0 5 10 15 20 MILES

The smooth surface of the glacier is banded from side to side by curving zones of darker color. These are the soiled zones due to the concentration of dust and small rock fragments which accumulated on the surface of each successive winter's snowfall. They thus differentiate the outcropping edges of the ice strata of which the glacier is composed.

When seen by the writer in 1911 and 1913 the ice was but very little crevassed, though a few cracks were open near the front of the lobe and in the upper part the latter were partially filled with snow. Interesting features seen in a few places were ice dikes 6 or 8 inches thick. These are formed by water freezing in the cracks. When subsequently there has been a little melting at the surface the parallel crystals may be raked out loosely with a pick. Similar but radial structures are seen in several places where circular cavities several inches in diameter have been filled by ice crystals growing convergently from the encircling ice wall toward the center of the cavity. Such features were called "gletschersternen," or "glacier stars," by Prof. Agassiz.

About 250 yards below the notch in the divide by which the glacier is reached from the south there is a zone extending laterally part way across the glacier in which there are many ice wells or moulins. These are vertical holes in the ice varying in diameter from 1 to 6 feet. Many of them, especially those into which streamlets of water plunge after flowing on the surface of the ice, appear to extend to the bottom of the glacier. Others from which the streams have been diverted are partially filled with snow. Soundings made by the writer in several of the wells with a cord and stone show depths ranging from 25 to 74 feet, the deepest being near the center of the main ice stream. These are regarded as measures of the thickness of the ice at these several points, since it seems probable that the water descends to the rock floor of the cirque before flowing away beneath the ice. These wells are arranged in lines transverse to the direction of ice flow and appear to have been developed along cracks which now at least are tightly closed though visible. At points where cracks were opened across the course of rivulets, or where rivulets developed across cracks already opened, percolation of water down the cracks may have initiated the thawing of holes which were gradually enlarged to their present dimensions. These wells were not noted farther down the slope in the central part of the glacier. It may be that along this zone is a position where successive cracks develop, though there are no open crevasses at this place. After one set of cracks and moulins have developed and moved a short distance down the slope the opening of new cracks in the former position may lead to the development

of a new set of moulins, giving new apertures by which the water is diverted to the base of the ice above the former line of wells. Subsequently these latter may become filled with snow and contracted by pressure until no openings remain. In a direction somewhat west of north from the notch in the divide, at the west side of the main current to the frontal lobe of the glacier is a mound of buff argillite fragments. About the head or south side of this are clustered many of these ice wells, so that this part of the glacier must be crossed with care.

Near the west side of this mound was seen a larger hole about 15 feet long shaped like a bathtub. This was filled with water to within a few feet of the surface and in the water floated a tiny iceberg. This is a good example of the cavities designated "baignoires," or "bathtubs," by Prof. Agassiz.[1] Soundings showed this "bathtub" to be 12 feet deep. It is not evident what would cause the development of so deep a cavity in the ice, as it appears not to be due to running water, at least the bottom and sides are now so tightly closed that the water is retained. Possibly it was once a moulin like those farther up the slope, which after being abandoned by the stream of water became partly filled with snow and tightly closed by refreezing. Prof. Agassiz describes baignoires in which there is no débris as probably due to the closing up of crevasses.

"Dust wells" are seen frequently. They are small vertical holes in the surface of the ice, a few inches in diameter, and a few inches deep with a little dirt at the bottom. At points where a small thin patch of dirt lies on the ice this dirt absorbs more heat from the sun than the surrounding ice and causes more rapid melting. Settling of the dirt with the melting of the ice deepens the hole until it reaches the limit of depth to which the sun's rays can penetrate the cavity.

The opposite, or protective, effect of rock débris upon the surface of the ice is well illustrated by the mound of rock fragments referred to above. This mound, which is 15 or 20 feet high, is probably principally of ice, but is completely covered by the rock fragments. Prof. Chaney[2] mentions such a "surface moraine of yellow slate," evidently the same rock-covered ice mound, as having been seen by him in 1895. Apparently many years ago a mass of rock fell onto the ice from the cliff at the back of the glacier and with the advance of the ice this has gradually moved forward. Meanwhile the surrounding ice surface has been lowered by melting while the ice beneath the rock pile has been protected from melting. As the surrounding ice disappeared, rock fragments slid down the sides of the mound so as to cover the ice core. From this mound a belt of scattered drift extends forward like a medial moraine to the front of the glacier.

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[1] System Glaciare, 1847, p. 100.

[2] Op. cit., p. 796.

Excepting at the point of the lobe, the glacier is bordered by a strongly marked marginal moraine 20 to 30 feet in height. At the extremity of the ice tongue the drift has been pushed over the cliff, though at present the ice is a short distance from the crest. One part of this moraine is largely composed of large and small fragments of lava (amygdaloidal trap rock). At a place west of the notch in the divide a bed of this rock extends to the top of the divide and there yields fragments which fall onto the ice. Such lava blocks are scattered all the way across the glacier from the place where these blocks fall to the moraine.

September 6, 1913, the writer attempted some crude measurements on the rate of movement in the glacier. On the west margin of the frontal lobe at a point about opposite the curve in the moraine a spike was set at 10.35 a. m. in the ice 45 inches in advance of a mark placed on the rock ledge. At 4.15 p. m. the distance, as nearly as could be determined, the spike having been slightly displaced by melting, had increased to $45\frac{1}{8}$ inches, an advance of one-eighth inch in 5 hours and 40 minutes. This was at the side of the lobe where it would seem that the movement would be much less rapid than in the center of the stream.

At a point near the extremity of the narrowed lobe a spike was set at 10.50 a. m. in the ice $37\frac{5}{8}$ inches in the rear of a mark on the rock ledge. At 4.03 p. m. this distance had decreased to $37\frac{1}{2}$ inches, indicating an advance of one-eighth inch in 5 hours and 13 minutes.

Sue Lake and Glacier.—Going westward from Chaney Glacier past the spur of the mountain one finds a beautiful little lake of blue lying in a rock basin in the next scallop of the great cirque. At the head of the lake is a tiny glacier lying at the foot of the great cirque wall. A strongly marked moraine 30 to 40 feet high borders the front of the ice at the edge of the lake, excepting for an interval where a narrow tongue of the ice projects through and into the lake. From this ice small bergs break off and float in the lake. A narrow cliff glacier lies on a bench in the south wall high above the lake. The outlet stream from the lake flows a few rods over rock ledges and then plunges 300 to 400 feet down the cliff to a lower compartment of the great cirque.

Shepard Glacier.—Crossing the creek which flows from Sue Lake and climbing over the ledges west of the outlet one reaches Shepard Glacier (fig. 21). This glacier was named for E. R. Shepard, of Minneapolis, who visited this region in company with Prof. L. W. Chaney in 1895 and subsequently.

This small glacier has an extent from northwest to southeast of about one-half mile and from southwest to northeast of about three-tenths of a mile. It occupies two levels of the cirque, the northern part being divided by a rock cliff. The main part cascades over

this cliff and in so doing is broken by great yawning crevasses which are closed again in the steeper slope below.

The front of each of the northern arms of the glacier is bordered by a morainal embankment, for which there is barely room at the tops of the cliffs. At the south side of the main glacier is a moraine piled 5 to 25 feet high. In places the ice margin is melted back 50 to 70 feet from this moraine. The dirt bands marking the edges of the ice strata show plainly. From the lower ice front a stream of water plunges several hundred feet down the cliff to the lower cirque floor.

Glacier southeast of Chaney Glacier.—Across the mountain wall on the southeast side of Chaney Glacier is another small glacier poking its nose into a little lake, which lies in a rock basin behind the lip of

FIG. 21.—SHEPARD GLACIER.

Photograph by W. C. Alden.

the upper cirque. When seen by the writer from the top of the cirque wall in August, 1911, this lakelet was dotted with floating masses of ice which had broken off from the glacier front. The water which overflows the lip of the cirque plunges 1,500 feet to a second lake in the head of the valley.

Former extent of the ice in Belly River Valley.—There are several other small glaciers in the heads of tributaries to the Middle and North Forks of Belly River Valley, last remnants of the great Belly River Glacier.

From an examination of the valley and of the deposits therein north of the international boundary it is known that at the last stage of the Glacial Period Belly River Valley was occupied by a great glacier extending from the Continental Divide northeastward across the international boundary into southern Alberta, a distance of at

least 30 miles (see map facing p. 32). No detailed study of the glacial phenomena has yet been made throughout this valley and its several tributaries, but there is reason for thinking that at a point 3 miles south of the forty-ninth parallel, or 10 miles from the Continental Divide, the ice in the valley was at least 800 feet thick.

GLACIERS IN THE NORTHWESTERN PART OF THE PARK.

Vulture Peak Glaciers.—An interesting area of glaciers and glacial phenomena is accessible either from a camp site in the upper part of Little Kootenai Creek Valley or from one at the head of the South Fork of Valentine Creek. From either site one can reach the top of the ridge between these two valleys by trail and go thence west over the divide. A somewhat more difficult and precarious climb may be made up along the face of the cliffs on either the north or the south side of the lake at the head of Little Kootenai Creek to the notch in the divide, from which the glaciers on the east slope of Vulture Peak are easily reached. The latter courses, however, are not to be recommended to inexperienced tourists. Between Vulture Peak and the ridge on the east is a considerable bench or rock floor whose relations suggest that it is part of the floor of an old cirque developed by a glacier in the Quartz Creek Valley from which the south wall was cut away by the headward stoping of glaciers which occupied Little Kootenai and Logging Creek Valleys. Three small lakelets occupy basins in this rock floor, and on the mountain slope to the west are the glaciers. The upper and larger one occupies two or more levels. The upper part has a steep surface and is much crevassed, and it extends down to the crest of a cliff and pushes its drift over to fall to the bench below. Farther south a narrow and much crevassed portion of the ice extends down over the cliff to that part of the glacier which spreads out on the bench around to the east. This part extends to the crest of a lower cliff or ledge and thrusts its load of drift over to fall below. The surface, especially near the front, is much broken by transverse and longitudinal crevasses. A morainal embankment extends from the foot of the ledge to the northwest side of the upper lakelet, showing that the ice has been more extensive. Below the south end of the ledge a separate tiny glacier extends down to the water in the upper little lake. The drainage from these glaciers is tributary to Quartz Creek.

On the ledges just east of this body of ice there is a fine display of the results of glacial abrasion in the form of smoothing, polishing, striating, and grooving (fig. 22). This is to be seen both on northeast-dipping rock surfaces and on vertical joint faces. Upward-curving striæ show where the ice rode up over ledges which projected in its path.

Farther south at the foot of the northeast slope of the mountain spur lies another small glacier. This is unique in that the water

from the northern part escapes across the upturned rock ledges and finds its way to and over the cliff at the head of Little Kootenai Valley, thus being tributary to Hudson Bay. The water from the southern part of the glacier flows southeastward along the strike behind a rock ridge and finally plunges down the cliffs at the head of Logging Creek Valley and becomes tributary to Columbia River and the Pacific Ocean. Because of this relation the proposal has been made to call this Two Ocean Glacier. Striæ on the ledges in front of this glacier show that it was formerly larger, and extended southeastward to the saddle between the heads of Little Kootenai

FIG. 22.—GLACIAL GROOVES, VULTURE PEAK.

Photograph by M. R. Campbell.

and Logging Creeks. The southerly trend of striæ in this saddle indicates that the ice joined a great Logging Creek glacier.

From the crest of the southeast spur of Vulture Peak there is a fine view of Vulture Glacier, which lies in an upper cirque in the south side of the mountain mass more than 3,000 feet above the lakes in the head of Logging Creek Valley. From the notch in this creek one can easily reach this glacier. The glacier and névé have a width from southwest to northeast of about four-fifths of a mile and a length from northwest to southeast of about seven-eighths of a mile. From the névé at the back the ice descends with a slope of 15° to 20°, which increases rapidly toward the front where several lobes cascade down over the ledges into notches in the lip of the upper cirque. The total

descent from the gaping bergschrund near the top of the névé slope to the end of the lowest lobe is 1,000 feet or more. The surface of the ice is smooth and banded from side to side with soiled zones marking the outcropping of the glacial strata.

That part of the glacier south of the end of the bifurcating ledge is so broken by crevasses as not to be readily crossed.

In places there are morainal deposits some distance below the ends of the frontal lobes. One of the small lobes has been considerably larger, as shown by the fact that there is a lateral moraine lying on a bench 50 or 60 feet higher and several rods farther south than the edge of the ice. The front slope of this lobe is about 27°.

On August 27, 1913, several attempts were made to measure the rate of ice movement. Not far from the end of the main lobe a spike was set in the ice at 2.30 p. m., 26⅛ inches in advance of a mark on the underlying rock. At 3.30 p. m. the distance had increased to 26⅝ inches, an advance of one-half inch in one hour. Markers set at the northeast side of the same lobe several hundred feet higher up showed no advance between 2.20 and 3.35 p. m. of the same day, thus indicating retardation of movement at the side of the lobe. Markers set at each side of the ledge which projects through the ice showed no appreciable advance between 1 and 2 p. m. of the same day. Evidently the flow lags about this ledge just as the recurved dirt bands seem to indicate. Near the southeast end of the ledge which bifurcates the glacier, markers were set at 1.30 p. m. on this day, and when reexamined at 2 p. m. the ice had moved one-half inch.

Carter Glaciers.—On the upper slope at the head of Valentine Creek near Jefferson Pass are two small glaciers designated the Carter Glaciers, in honor of the late Senator Carter of Montana. The most southerly one is about one-fourth mile in extent from back to front and about three-fourths of a mile wide from northwest to southeast. The surface is smooth and shows but few crevasses. Though so small a glacier, the front is bordered by a morainal embankment rising in places 50 feet above the ice on the inside and 100 feet above the rock on the outside. The ice front has, in part, been melted back 200 feet from the summit of the ridge, but elsewhere it is pressed snugly against the moraine.

A short distance farther north there is a somewhat larger compound glacier consisting of a lower main body, much crevassed because of the steepness and irregularity of slope, and two distinct smaller ones higher up on the cliff. The upper glacier cascades down to the lower one. Along the north front of this is a strong moraine with reliefs of 60 to 70 feet on the inside and 80 to 100 feet on the outside. At the center of the front the ice thrusts its load of drift over the crest of a 50-foot cliff. The height and position of the moraine on the north

side indicate that at some time the glacier has had considerably more bulk than it now has.

On the north slope of Mount Carter is a small glacier more resembling the valley type in that it extends through the contracted opening of the cirque and cascades down the steep slope in a long, narrow

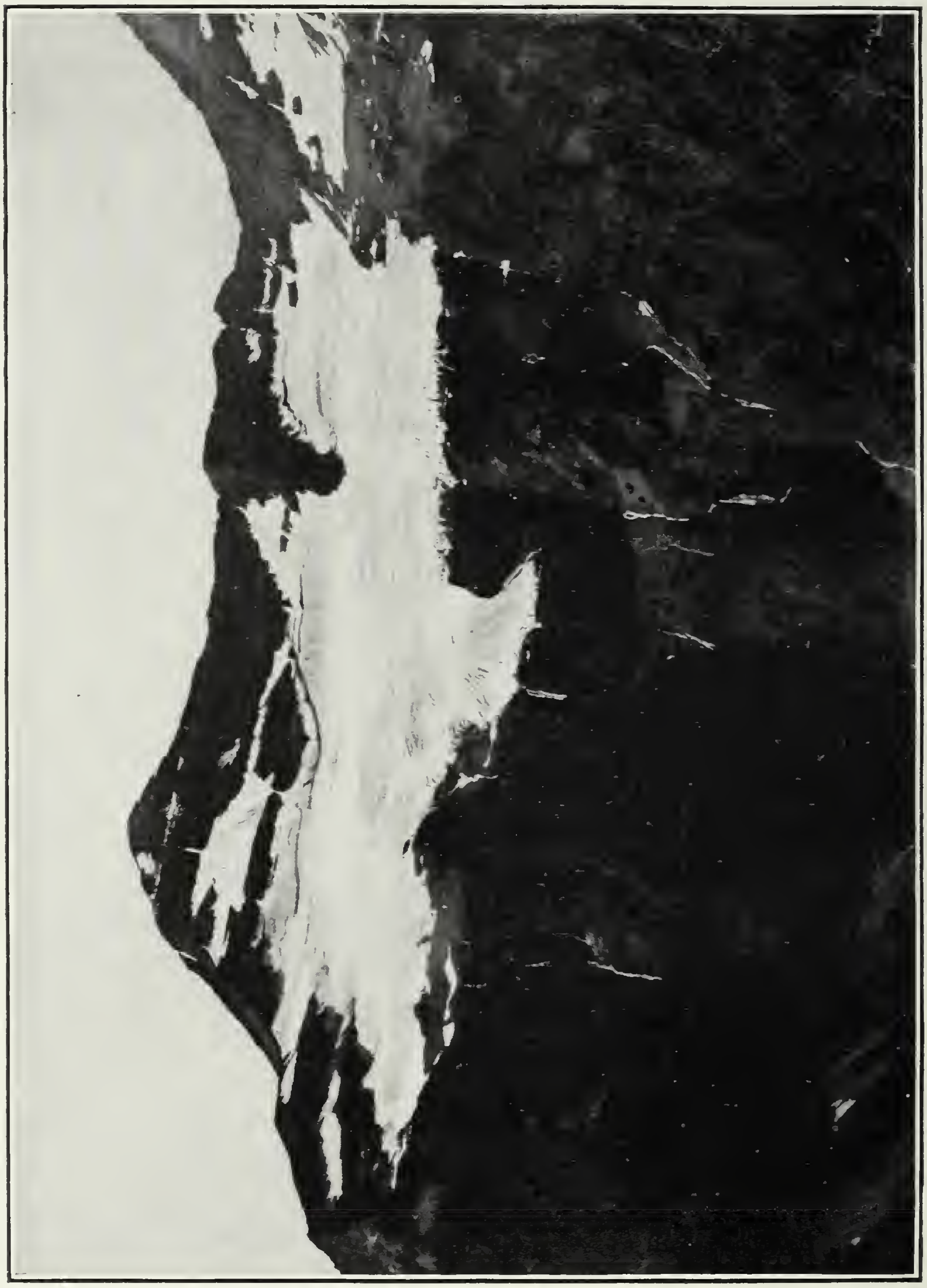

FIG. 23.—RAINBOW GLACIER, RAINBOW PEAK IN BACKGROUND.

Photograph by M. R. Campbell.

tongue. The ice has shrunken away from its strong lateral moraine. At the front of the cascading tongue the drift is dumped down the steep slope. It is this glacier which furnishes most of the glacial silt which renders so milky the South Branch of Bowman Creek as seen from the trail leading to Brown Pass.

Rainbow Glacier.—From the mountain ridge east and north of Vulture Peak there is a fine view across the head of Quartz Creek Valley to the Rainbow Glacier nestling in an upper cirque which scallops the mass of Cerulean Ridge on the east flank of Rainbow Peak (fig. 23).

This glacier and its névé has a breadth from northeast to southwest of nearly 1 mile and a length from northwest to southeast of 1⅕ miles. The entire lower half is much crevassed as though it were moving down over a steep and irregular slope broken by steps or ledges. The maximum descent of the ice is about 2,000 feet. At about the middle of the front of the glacier a tongue about 100 yards wide extends by cascading down to a ledge about 200 feet below the main front. Excepting in the south part, where a moraine embankment borders the ice, the glacier crowds forward to the very verge of the cliff. The ice in places seems to overhang the edge, and abrupt ice cliffs suggest that great masses of ice break off and are precipitated to the abyss over 2,000 feet below.

Olson Creek glaciers.—Looking southward from Brown Pass one sees in the great upper cirque a glacier which has a width of nearly seven-eighths of a mile and which descends about 1,200 feet or more in the three-fourths mile of its length. This may be reached by an easy climb of a few hundred feet from the pass. When somewhat larger than it was when seen by the writer in August, 1913, this glacier pushed its terminal moraine near the crest of the cliff which drops to the head of the valley below. Since that time the ice has shrunken somewhat from the moraine. More or less detached portions of the glacier lie on benches in the cirque wall above the main mass. Near the front the ice is broken by crevasses, some of which are 10 to 15 feet wide at the top and 15 to 20 feet deep. In the walls of these crevasses the banding of the ice is seen to dip backward upstream at low angle. The ice exposed here carries little or no included drift. At one point where the foot of the glacier is just at the top of a ledge the ice rides free a foot or so above the rock for a distance of at least 25 to 30 feet back from the margin. Looking into this space one sees but little drift in the bottom of the ice. Where the ice is grinding, polishing, and scoring the rock ledges there appear, so far as can be seen, to be but a thin layer of fine rock flour and small fragments between the clear ice and the rock surface.

These and other small glaciers in the cirques farther east are the only remnants of the great glacier which during the last great extension of the ice occupied Olson Creek Valley and was tributary to the one in Little Kootenai Creek Valley. To this were also tributary the glaciers occupying the head branches of this valley and the valleys of Valentine and Boundary Creeks. It is known that at the last, or Wisconsin, stage of glaciation this great trunk glacier extended northward into southern Alberta. Ten or twelve miles north of the

boundary line the deposits of this glacier pass under those of the great continental ice sheet. Observations of glacial striæ high upon the mountain slopes at the head of Waterton Lake indicate that the ice was at least 1,500 feet thick opposite the mouth of Olson Creek and it was probably even thicker than this.

Boulder Glacier.—Looking westward from Brown Pass across the great cirque at the head of Bowman Creek Valley, one sees, high up at the top of the great cirque wall, two small glaciers. The larger one of these is Boulder Glacier (fig. 24). This may be reached from the pass, but the route is somewhat hazardous and is not to be recommended for inexperienced climbers. The bench on which this glacier rests is formed by a lava bed. This rock emerges from beneath the

FIG. 24.—BOULDER GLACIER, KINTLA PEAK IN BACKGROUND.
Photograph by W. C. Alden.

eastern margin of the ice and extends thence to the crest of the wall of the lower cirque. In this interval there is a remarkable exhibition of the effects of glaciation produced when the ice had a somewhat greater extent. The ledges are scored with striæ and so smoothly rounded and polished as to offer in many places precarious footing (fig. 25). The glacier extends westward through the gap in the mountain crest. The disposition of the zones marking the stratification and also the general surface slope indicate that the ice now moves toward the cliff on the north side of the gap. For a short distance in the midst of the gap there is a strong morainal embankment piled 25 to 35 feet high near the foot of the mountain ridge on the north. This moraine, which is composed of intermingled rock flour and partly worn and partly angular rock fragments ranging in size from a fraction of an inch to 6-foot blocks, is continuous around the

west side of the mountain ridge and also about the western part of the glacier.

Emerging from beneath the western part of the glacier the lava bed extends westward and northward as the floor of two broad gaps until it is cut off at the crests of the walls of two lower cirques in which head branches of Kintla Creek. The surface of this uneven textured, vesicular rock is finely glaciated, exhibiting striæ, gouges, and beautifully rounded and polished roches moutonnées.

Boulder Glacier, together with four tiny glaciers in scallops high up in the walls of the great cirques farther southwest and the cascading glacier on the northeast slope of Mount Carter, are the only remnants of the great glacier which once occupied the valley of Bowman

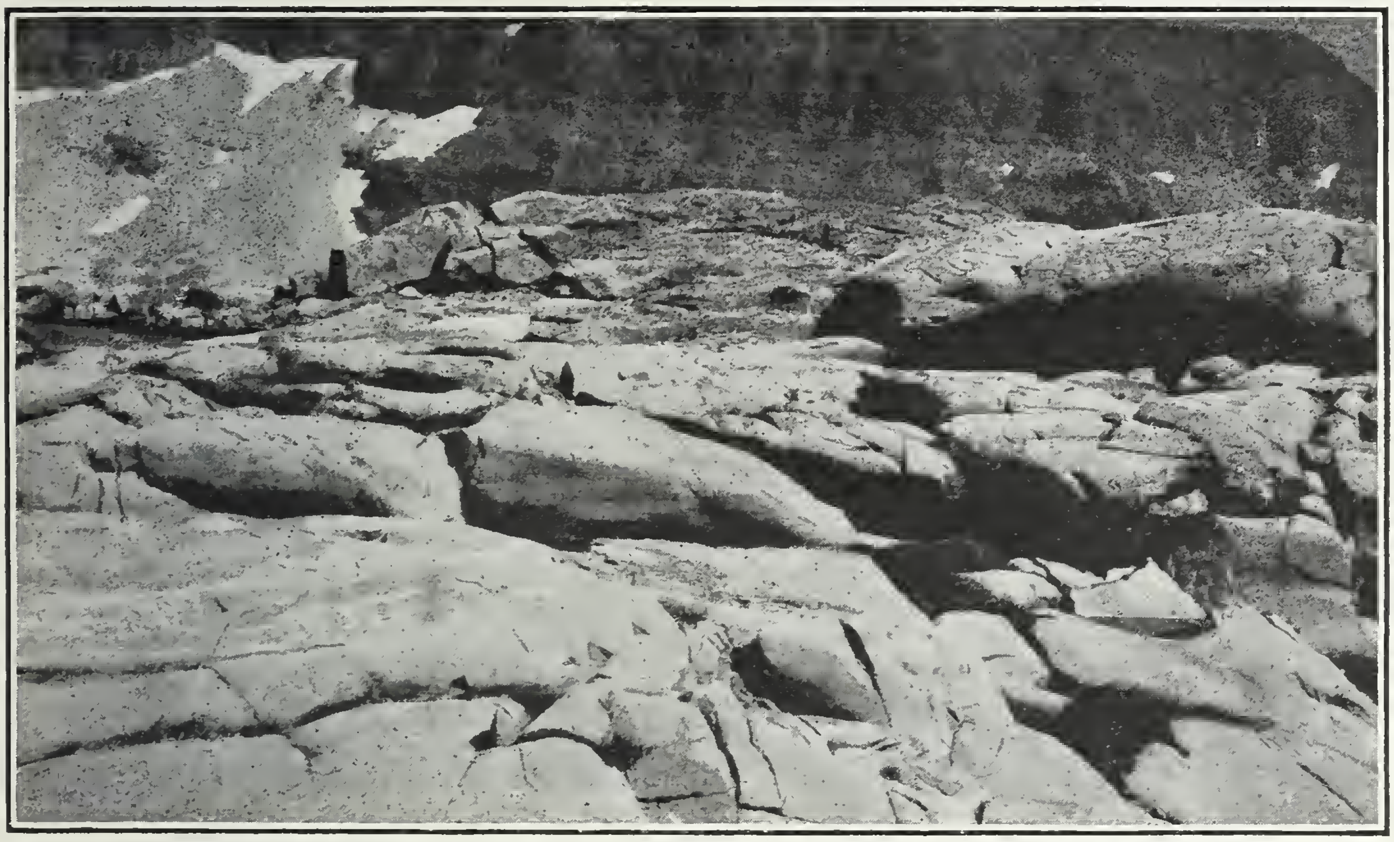

Fig. 25.—Glaciated lava bed in front of Boulder Glacier.

Photograph by W. C. Alden.

Creek and Lake. On the north slope facing the lake, opposite Rainbow Peak, the writer observed horizontal glacial striæ evidently produced by the great valley glacier 1,100 feet above the lake. The lake opposite this point is 150 feet deep, so that it is known that the great valley glacier must have had a thickness of at least 1,200 or 1,300 feet opposite Rainbow Peak.

AGASSIZ AND KINTLA GLACIERS.

From the mountain slope west of Boulder Glacier one gets a distant view of Agassiz Glacier, one of the finest in the park, on the northeast slope of Kintla Peak (fig. 26). This glacier has a breadth of 1.3 miles. From the broad main part of the mass a narrow tongue extends nearly 1,200 feet lower down the slope. This gives the glacier a length from southwest to northeast of 1.8 miles. The

ice in this lower tongue is much crevassed. West of this lobe a morainal embankment borders the ice. Agassiz Glacier has a vertical extent of about 2,000 feet, the lowest point being about 5,800 feet above sea level. The glacier is said to be accessible from Upper Kintla Lake.

On the opposite, or west, side of Kintla Peak is Kintla Glacier (fig. 27), having a breadth of more than 2 miles, but an area about the same as Agassiz Glacier.

EARLY GLACIAL HISTORY OF THE REGION.

Wisconsin stage.—In the above descriptions of the glaciers of the park reference has been made to former greater extension of the ice.

Fig. 26.—Kintla Peak and Agassiz Glacier.

Photograph by W. C. Alden.

The geological studies in and adjacent to the park have developed evidence that there were at least two and possibly three different times when the glaciers extended far down the valleys and out onto the neighboring plains. These extensions of the mountain glaciers were probably contemporaneous with the development and deployment of the great ice sheets which covered so large a part of the North American Continent during the several stages of the Glacial Period, or the Great Ice Age. As is the case in the study of the phenomena of the continental ice sheets, so also the study of Rocky Mountain glaciation has developed evidence showing that the epochs when climatic conditions were such as to cause great extensions of the glaciers alternated with epochs when conditions were similar to those of the present so that the glaciers melted away and the valleys were occupied as now by streams.

On the map facing page 32 an attempt has been made to represent graphically conditions as they were in the mountains and on the plains east of the park during the maximum of the last great stage, known as the Wisconsin stage, of glaciation. On this map the mountain valleys are shown filled with ice 1,500 to 2,500 feet thick, the

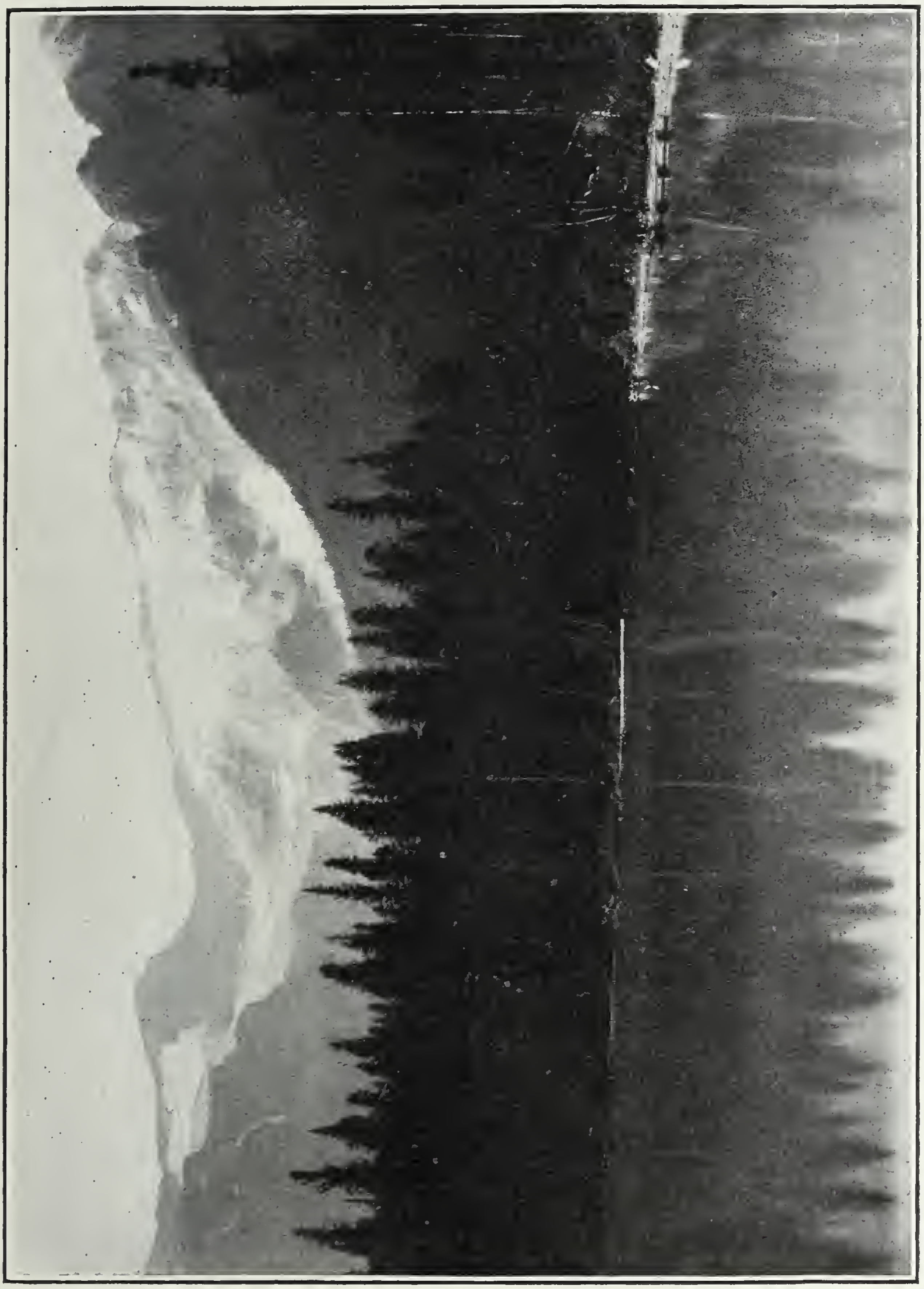

FIG. 27.—KINTLA GLACIER FROM UPPER KINTLA LAKE.

Photograph by Bailey Willis.

glaciers heading in the many cirques and extending thence down the valleys and out onto the plains. The crests of the dividing mountain ridges are represented as bare, although they were probably in reality more or less mantled with snow and ice. The map shows the general relations of the mountain glaciers to the border of the great Keewatin glacier which centered on the Keewatin plateau west of Hudson

Bay, and also the temporary lake, Cut Bank glacial lake, which resulted from the blocking of Cut Bank Creek by the ice.

Streams of ice heading in the mountain valleys now drained by Two Medicine and Badger Creeks and their tributaries coalesced and spread out on the plain as a great piedmont glacier, known to geologists as the Two Medicine glacier. This glacier had a maximum length of about 48 miles and a breadth of 30 miles. The knolled and pitted surface of its morainal deposits may be seen between the railway and the flat-topped ridge 5 miles north of Glacier Park station. North of this, ice in Lake Creek Valley coalesced with a glacier in Cut Bank Valley. Morainal deposits of these glaciers are crossed by the automobile road leading from Glacier Park station to St. Mary Lakes.

St. Mary Valley was occupied by a great trunk glacier which so nearly filled the valley where the lakes now lie that it deposited a well-marked lateral moraine at the top of the ridge on the east 1,200 foot or more above the lower lake. So effectually did this ridge serve as a diverting dam that the greater glacier, instead of extending directly eastward onto the plains, was turned northward into southern Alberta. Where the ridge is lower, east of Babb, the ice did extend onto the upland, and a lobe deposited a strongly marked moraine, enclosing the basins of Duck and Goose Lakes. In St. Mary Valley about 1 mile south of the boundary the drift of the St. Mary Glacier, which is composed entirely of material from the mountains, is overlapped by drift of the continental, or Keewatin, glacier, which contains granite boulders from the region of Hudson Bay. Tributary to St. Mary Glacier were glaciers in the valleys of Kennedy, Swiftcurrent, Boulder, Red Eagle, and Divide Creek Valleys.

Drift of the glaciers which at the same time occupied Belly River and Waterton Lakes valleys is also overlapped by drift of the continental glacier, in the one valley about 9 miles and in the other about 12 miles north of the international boundary.

The phenomena in the western part of the park indicate that the valleys of Kintla, Bowman, Quartz, Anaconda, Dutch, and Camas Creeks and those farther south were also occupied by great valley glaciers during the Wisconsin stage of glaciation. The actual extent of these glaciers has, however, not yet been fully determined. Terminal moraines have been found in Bowman, Quartz, and Anaconda Creek valleys, but it has not been determined that those seen farthest downstream mark the limit of extension of the glaciers at the Wisconsin stage. The best examples of these deposits are the moraines crossed by the trail below Bowman Lake and above and below Middle Quartz Lake.

The great intramontane basin which is represented by West Flattop, Flattop, and Granite Park and similar tracts, and into the bot-

tom of which are cut the valleys of McDonald and Mineral Creeks, is believed to have been occupied by a great central mass of ice which discharged principally southwestward by the McDonald Creek Valley.

To this stage of glaciation was probably due some deepening of the previously-existing stream-cut valleys and the broadening and smoothing of sharp V-shaped cross profiles, produced by stream erosion, to the wider and beautifully rounded U-shaped profiles now seen (fig. 1, *A* and *B*). Also most of the excavation of the remarkable cirques which scallop the slopes of the great mountain masses was accomplished at this stage.

Pre-Wisconsin glaciation.—The Wisconsin stage of glaciation was preceded by a long period during which the glaciers were probably absent or much reduced in size, a time during which the streams were actively engaged in sculpturing the great mountain mass, in deepening the valleys, and in eroding and washing away the soft rocks underlying the adjacent plains.

Prior to this period of valley cutting, the plains bordering the mountains on the east were in general some hundreds of feet higher than at present and not so much broken by hills and valleys. In the area between the Great Northern Railway and the international boundary there are numerous remnants of the former high levels of the plains. These are the flat tops of the ridges which stand between the several branches of Milk River, St. Mary River, and Cut Bank Creek (the stippled tracts shown on the map facing page 32). Examination of the deposits which underlie these flat tops and which overlie the upturned and beveled edges of the sandstones and shales forming the bulk of the ridges shows that a large part at least are of glacial drift derived from the mountains. The relations show that long ago, before the valleys which now separate these ridges were eroded and when the various remnants yet formed a continuous, nearly flat plain, there was a stage of glaciation when the ice heading in St. Mary Valley and the tributary valleys was not diverted northward by St. Mary Ridge and the great trough in which the St. Mary lakes and river now lie, but that the tributary glaciers united in a great piedmont glacier, which spread directly eastward onto the uneroded plain. Ice from Cut Bank and Two Medicine Valleys probably also joined in this extension. Over a large area south of the railway, however, no remnants of these early glacial deposits have been found. They were probably almost entirely removed during the long interval when stream erosion was going on or were obscured by being overrun by the great Two Medicine glacier of the Wisconsin stage.

In places, as, for instance, on the ridge north of Lower Two Medicine Lake and on St. Mary Ridge, the long exposure of this old drift

to the weather has resulted in the limestone pebbles and bowlders being removed from the upper part by solution and the calcium carbonate being carried down by the percolating waters and deposited as a cement, binding the lower part of the drift into a hard conglomerate.

The relatively great age of this early glacial drift may be inferred from the fact that even those tributaries of Milk River which received none of the mountain water have cut valleys several miles in width and hundreds of feet deep below the horizon of the former high-level, drift-covered plains. It is believed that St. Mary Valley was deepened at least 800 or 1,000 feet during the interval between the earlier and the Wisconsin stages of glaciation, that the tributary mountain gorges and other valleys were correspondingly eroded, and that a considerable part of the sculpturing of the great mountain mass was accomplished during this period of stream activity. Compared with the time which has elapsed since the Wisconsin stage of glaciation the interval of deglaciation must have been very long.

In the above discussion the pre-Wisconsin interval has been referred to as a single uninterrupted epoch of deglaciation and erosion. There is, however, definite evidence that it was not such. There are, east of the mountains in the Blackfeet Indian Reservation, remnants of three sets of plains above the levels of the present drainage lines, all of these older than the drift of the Wisconsin stage of glaciation, and on two of these are deposits of pre-Wisconsin glacial drift. The third set of these plains comprises the broad valley bottoms, onto which the glaciers of the Wisconsin stage encroached and into which the present streams have cut their sharp narrow channels.

It is thus probable that there were two distinct earlier stages of glaciation of the mountains separated from each other and from the Wisconsin stage by long intervals of deglaciation and stream erosion. Some of these stages may have resulted from or have been accompanied by general elevation or depression of the region.

Within the limits of this brief paper there is not opportunity to discuss all the evidence bearing on this question. For further details reference should be made to other papers by the present writer and others.[1]

[1] Pre-Wisconsin glacial drift in the region of Glacier National Park, Mont., by Wm. C. Alden, Bull. Geol. Soc. Am., vol. 23, pp. 687-708, 1912.

Ditto, by Wm. C. Alden and Eugene Stebinger, Bull. Geol. Soc. Am., vol. 24, pp. 529-572, 1913.

The Montana lobe of the Keewatin ice sheet, by F. H. H. Calhoun, Prof. Paper U. S. Geol. Survey, No. 50, 1906.

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